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THE CORRELATION OF RADON CONCENTRATION WITH VARIOUS BUILDING ATTRIBUTES AT U.S. AIR FORCE BASES

A Thesis

Submitted to the Faculty

of

Purdue University

by

Scott M. Nichelson

In Partial Fulfillment of the
Requirements for the Degree

of

Master of Science

August 1992

This work is dedicated to my wonderful wife and typist, who tolerates my endless pursuit of knowledge, and to our unborn child, who provided the much needed inspiration to finish this work on time!

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The views and opinions expressed in this publication are those of the author, and not necessarily those of the United States Air Force or the Department of Defense.

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ABSTRACT

Nichelson, Scott M. M.S., Purdue University, August 1992. The Correlation of Radon Concentration with Various Building Attributes at U.S. Air Force Bases. Major Professor: Robert R. Landolt.

A statistical analysis was conducted on radon data from the United States Air Force's Radon Assessment and Mitigation Program (RAMP). The data came from 1-y alpha track detectors which were deployed at 15 U.S. Air Force installations worldwide. Sample sizes at the different installations ranged from 373 to 5801. Radon concentration was modeled at each installation utilizing multi-factor analysis of variance (ANOVA) with the following building attributes as independent predictor variables: type of structure, age, type of foundation, number of stories, type of air conditioning, type of fuel, type of heating, type of water, floor where sampler was placed, the presence of a sump pump on the lowest level, and the presence of a drain on the lowest level. In addition, a trend analysis was conducted among class levels of each individual attribute for each installation.

The attributes age, type of structure and their interaction were the most strongly correlated to radon concentration, generally accounting for about one-fourth to

one-half the variation of radon concentrations in the models. Other attributes which exhibited a weaker correlation with radon concentration include: type of foundation, type of fuel, the number of stories, and the floor where the sampler was placed. In general there was no correlation between radon concentration and the attributes type of water and presence of a drain or sump pump at the lowest level. The coefficients of determination, R^2 ranged from 0.191 to 0.627 which is rather poor for predictive uses and indicates other factors, such as the underlying geology, may be more important then the attributes examined in this study.

The trend analyses indicated that the following attributes tend to yield the highest radon concentrations: single family homes, single story structures, and structures built during the 40s, 50s and 60s.

INTRODUCTION

In the past few years the problem of elevated radon levels indoors and the potential risk to building occupants have received increased attention. Radon, ^{222}Rn, is a naturally occurring radioactive gas which arises from the decay of the uranium series. Since it is a gas, it can diffuse throughout the soil and enter any airspace, including basements, crawl spaces, and indoor living areas. Once indoors, radon in a building has only a limited volume of air with which it can mix, thus indoor radon concentrations are usually higher than those outdoors. Radon gas decays into daughter products which can build up in an enclosed space and become lodged in lung tissue when inhaled. It is these daughter products that continue to decay giving off radiation which can then lead to the development of lung cancer.

The United States Air Force (USAF) is concerned about the increased risk of developing lung cancer by persons exposed to elevated levels of radon in their domiciles and in their places of work. To assess the extent of the radon problem in Air Force structures world-wide and to mitigate those structures found to have elevated radon levels, the

USAF implemented the Radon Assessment and Mitigation Program (RAMP). (Ge 91)

The objectives of RAMP are (1) to identify all Air Force structures that have radon levels above the U.S. Environmental Protection Agency's (EPA) recommended action level of 4 picocuries per liter (pCi/L) and (2) to mitigate those structures with high radon levels to reduce the indoor radon levels. (Mah 87)

In order to achieve the first objective of RAMP, the U. S. Air Force is conducting the program in three assessment phases: (1) an initial screening phase to identify bases that may have a problem, (2) a detailed assessment phase to identify structures that require mitigation by monitoring all structures on base, and (3) a post-mitigation phase to verify that radon levels have been reduced below the EPA action level after they have been mitigated. (Ge 91)

In phase I of RAMP, which was conducted from December, 1987, through February, 1988, approximately 35 alpha track detectors (ATD) were deployed at each of 135 installations world-wide for a period of 90 d. Based on these results, the installations were placed in one of three probability categories (dealing with the probable need for mitigation): "high probability", any base having at least one sample with a radon concentration greater than 20 pCi/L; "medium probability", any base having at least one sample with a radon concentration greater than 4 pCi/L but less than 20 pCi/L; and finally "low probability", any base having no samples above 4 pCi/L.

In phase II of RAMP, which began in late 1988 and is scheduled to be completed in 1993, detailed assessment surveys are being conducted at high and medium probability installations. These surveys are further subdivided into two phases, housing and administrative buildings, with the housing phase receiving the greater sampling priority. No further actions were taken for low probability installations.

Detailed assessment surveys at a high probability installation consisted of two ATDs deployed side-by-side in all structures on the installation except aircraft hangars, storage warehouses, gymnasiums, camp and recreational structures, and any other structure that is not normally occupied at least 4 h per day. One ATD was analyzed after 30 d, so that structures with radon concentrations greater than 20 pCi/L could be quickly identified and mitigated. The other ATD was left in place for a 1-y period and it was used as the basis for mitigation, provided the 30-d detector result did not exceed 20 pCi/L. In addition to radon concentration measurement, information about various building attributes, such as age, type of structure, type of foundation, etc., was recorded and entered into a master data base.

Detailed assessment surveys at the medium probability installations are being conducted in a manner similar to the high probability installations, except that only one ATD is deployed per structure for a period of 1 y.

Detailed assessment surveys for all but administrative buildings have either been completed or are under way at the high and medium probability installations. (Mah 91)

While the primary objective of RAMP is to find and mitigate all Air Force structures to the 4-pCi/L EPA action level, the RAMP data base offers an excellent opportunity to perform a statistical analysis on the data. The RAMP data base is unique in that it contains a relatively large number of samples in a relatively small area. Most of the surveys in the literature have either a large number of samples ($n > 300$) taken from a large geographical area, such as the United States itself, or have a relatively small number of samples ($n < 300$) from a relatively small area, such as a state or a county. Therefore a secondary objective for RAMP, and the objective of this research, was to determine if any of the building attributes could be correlated with and modeled for radon concentrations. A secondary objective of this research was to conduct trend analyses between class levels of each individual attribute.

LITERATURE REVIEW

Radon Characteristics

There are three naturally occurring isotopes of radon. Radon-222 is produced from the decay of ^{238}U daughters, ^{220}Rn is produced from the decay of ^{232}Th daughters, and ^{219}Rn is produced from the decay of ^{235}U daughters. Due to the low abundance of ^{235}U relative to ^{238}U and the short half-life of ^{219}Rn, that isotope is of negligible importance in most practical situations. Radon-220 and ^{222}Rn are produced at approximately the same rate; however, ^{220}Rn has such a short half-life that its atmospheric concentration is insignificant compared to the 2.4×10^9 Ci of ^{222}Rn which is released annually to the atmosphere. (Co 79)

Radon is a colorless and odorless gas, ubiquitous in nature, and the only gaseous member of the ^{238}U decay chain. Since ^{222}Rn is a noble gas, it can diffuse away from its parent, ^{226}Ra, which may be chemically bound to a substance. Radon-222 diffusion is limited by its 3.8-d half-life and the porosity of the soil. (NCRP 84) It is this diffusion mechanism which allows radon to reach cracks in building foundations and to concentrate within buildings. Other methods of entry include the water supply, natural gas supply, and radium-containing construction materials such as concrete, gypsum wallboard, masonry walls, and phosphate slag. (Ep 86)

Radon Measurement

There are three main detectors for measuring radon and radon concentrations: continuous radon monitors, alpha track detectors, and charcoal canisters.

Continuous radon monitors utilize a scintillation cell which is counted on a photomultiplier tube. They are used primarily to monitor radon concentrations continuously for periods of time ranging from hours to months. They are used extensively in research, where data are taken from relatively few data points (normally less than 10). Their biggest disadvantage, however, is cost, since many more hundreds of measurements can be taken with the other two methods for the same cost.

Alpha track detectors (ATD), are long term integrating passive detectors. They typically contain a small amount of plastic which is damaged by alpha particles from the decay of radon and its daughters. These damaged areas, when etched by caustic solutions, leave tracks that can be observed with a microscope. The density of the tracks is proportional to the radon concentrations. (Ye 91) The main advantage is that these detectors can be deployed for periods up to 1 y, are completely passive, and are less sensitive to temperature and humidity changes than charcoal canisters. (Mar 91)

Charcoal canisters are short term integrating radon detectors, which have been used extensively in residential radon measurements. The two types which are commonly used are the diffusion barrier charcoal absorption canister (DBCA) and the bare charcoal canister. A diffusion barrier generally increases sampling time and improves averaging of the radon concentrations (Mar 91). Deployment time typically ranges from 2 d for a bare canister to 7 d for a DBCA canister.

Factors Affecting Indoor Radon Concentration

A multitude of factors can contribute to the variability of radon concentration in residential and commercial buildings. Many researchers have studied the effects of geographical location, type of building substructure, type of residential home, age of the building, presence of a sump pump, presence of a crawl space, type of heating fuel used, location of detector, window being open or closed, the floor and location of the sampler, among others. Most of the researchers determined if the variable being studied was significant, and if so then determined whether the variable had either a positive or negative effect on radon concentrations. A few studies used linear regression to attempt to further quantify the relationships between the variables. Table 1 contains a general listing of such studies including the number of samples in the survey, measurement method, and exposure duration of the detector.

Table 1 Summary of Radon Concentration Correlation Studies

Study	Number of Samples	Measurement Method	Exposure Time Period
Co 86	453	ATD	1 year
Co 88	73,500	DBCA	7 days
Co 91	70,000	DBCA	7 days
Bi 91	3021	ATD	~30 days
Li 90	310	ATD	1 year
Hu 89	125	charcoal canister	unknown

Type of Foundation/Substructure

The type of foundation or substructure in a building may be related to radon concentration in that certain types of foundations may provide better routes of entry into buildings. Liu et al., found that homes with concrete slab foundations had the highest radon concentrations. (Li 90) Cohen, on the other hand, found that homes with basements had the highest radon concentrations. (Co 86)

Age

The age of a structure has a curious relationship with radon concentrations. In relatively new homes, for example less than 10 y old, radon concentrations could be higher than in older homes due to the "tightness" of a building. As a building ages, however, there may be two or more competing factors relating to radon concentrations: (1) as a building ages, it gets less tight due to the development of cracks, and therefore radon concentrations would tend to drop with age, and (2) as a building ages and settles, more cracks may develop in the foundation allowing more radon to diffuse into the building, thus increasing radon concentrations. Both Liu et al., and Cohen found that homes less than 10 y old had the highest radon concentrations. (Li 90, Co 91) In 1986, however, Cohen found that homes in the 30-39-y old range had the highest radon concentrations. (Co 86) Harrell and Kumar, and Bierman and O'Neill, found contradictory results concerning age and radon concentrations, that is in some instances radon concentrations were higher and in some instances radon concentrations were lower. (Ha 89, Bi 91)

Type of Home

The type of home may be related to radon concentration due to the ratio of building volume to soil surface area under the foundation. In other words, one might expect radon concentrations to be lower in a multi-unit apartment complex. Liu et al., indeed found that single family homes had the highest radon concentrations. (Li 90)

Sump Pump

Having a sump pump in the lowest level would be expected to increase radon concentrations due to a penetration in the foundation. Harrell and Kumar, and Bierman and O'Neill, however, found that there was no significant statistical difference between having and not having a sump pump at the lowest level. (Ha 89, Bi 91)

Drain

Similar to the sump pump, having a drain in the lowest level would be expected to increase radon concentrations due to the decreased resistance in the foundation to radon diffusion at that point. Harrell and Kumar, and Bierman and O'Neill, however, again determined that there was no statistical difference between having and not having a drain in the lowest level. (Ha 89, Bi 91)

Sampler Location

Since radon emanates from the soil and is heavier than air, it would be expected that radon concentrations would be higher on the lower floors of a building. Bierman and O'Neill, and Cohen found that radon concentrations are significantly higher in basements, while Cohen and Gromicko determined that radon concentrations were 2.5 times higher in the basement as opposed to the first floor. (Bi 91, Co 81, Co 88)

Windows

Opening the windows for a significant time period of the day may lead to reduced radon concentrations due to an increase in fresh air and a lowering of a negative pressure situation in a building. Liu et al., found that opening the windows can reduce radon concentrations significantly. (Li 90) Cohen and Gromicko determined that opening the windows can reduce radon concentrations by a factor of 2.5. (Co 88)

Number of Floors

In the same manner as the type of building, the number of floors in the building could be related to radon concentrations. It could be expected that buildings with a greater number of floors would have lower radon concentrations. Cohen determined that homes with two stories, including a basement, had the highest radon concentrations. (Co 86)

Air Conditioning

Having central air conditioning would be expected to increase radon concentrations due to increased tightness in a building. Surprisingly Bierman and O'Neill, found that homes with central air conditioning had lower radon concentrations. (Bi 91)

Summary

A summary of the effects of these variables as reported in the literature is found in Table 2.

Table 2 Summary of Building Attributes in Relation to Radon Concentrations

Variable	Study	Results
Substructure type	Li 90	Concrete slab homes have highest radon concentrations
	Co 86	Houses with basements have highest radon concentrations
Age	Li 90	Homes less than 10 y old have highest radon concentrations
	Co 91	Homes less than 10 y old have highest radon concentrations
	Co 86	Homes 30-39 y old have highest radon concentrations
	Ha 89	Contradictory results
	Bi 91	Contradictory results
Type of home	Li 90	Single family homes have higher radon concentrations
Sump pump	Ha 89	Not statistically significant
	Bi 91	Not statistically significant
Drain	Ha 89	Not statistically significant
	Bi 91	Not statistically significant
Floor sampled	Bi 91	Basement measurements are higher
	Co 88	Basement measurements are 2.5 times higher
	Co 91	Basement measurements are higher
Windows opened vs. closed	Co 88	Open windows reduce radon concentrations by a factor of 2.5
	Li 90	Open windows can reduce radon concentrations significantly
Number of floors	Co 86	Two and three floor houses (including basements) are higher than others
Air conditioning	Bi 91	Central air conditioning lowers radon concentrations

MATERIALS AND METHODS

Data Collection

All of the radon data in this study came from the United States Air Force's Radon Assessment and Mitigation Program, Phase II; detailed assessment surveys, which were conducted at four high probability Air Force installations and 11 medium probability Air Force installations as defined in the Introduction section. Of these 15 installations, 10 are located within the continental United States, three are located in the Pacific Ocean region, and two are located within Europe or the Atlantic Ocean region. A listing of the installations, location, and sample size is given in Table 3.

Passive integrating alpha track radon detectors were deployed in almost every home or building on the installation which was normally occupied for 4 or more h during a typical work day. These detectors were deployed by contractor personnel for a 1-y period between 1988 and 1991. They were retrieved and sent to Geomet (Geomet Technologies, Inc., 20251 Century Boulevard, Germantown, MD 20874) for processing and analysis. At high priority bases a second detector was deployed and analyzed after a 30-d period. In this study, however, these data are ignored to eliminate seasonal

Table 3 Listing of Installations Studied

Installation	Location	Number of Annual Samples
Grissom AFB	Peru, Indiana	633
Wright-Patterson AFB	Dayton, Ohio	2487
Chanute AFB	Champaign, Illinois	1869
Grand Forks AFB	Grand Forks, North Dakota	2520
Ellsworth AFB	Rapid City, South Dakota	1398
Peterson AFB	Colorado Springs, Colorado	684
USAF Academy	Colorado Springs, Colorado	1207
Bergstrom AFB	Austin, Texas	941
Nellis AFB	Las Vegas, Nevada	1723
Edwards AFB	Rosamond, California	2342
Aviano AB	Aviano, Italy	373
Lajes AB	Azores (Portugal)	745
Andersen AFB	Guam	1795
Yokota AB	Tokyo, Japan	1431
Kadina AB	Okinawa (Japan)	5801

variation and to provide for a common basis for comparison. In addition a separate analysis of each installation was conducted in order to minimize geographical biasing.

Along with the radon concentration, several other pieces of information were collected including "housekeeping variables", such as detector serial number, building number, room number, and building attributes, and were entered into a master data base. Table 4 lists the building attributes that were utilized in this study, their coding, and their abbreviations which are used later in this section.

Table 4 List of Building Attributes

Attribute	Coding	Potential Values
Type of Structure	1	Single family house / detached
(struct)	2	Single family house / attached
	3	Apartment building
	4	Child care center
	5	Dormitory
	6	Transient living facility
	7	School
	8	Office building
	9	Hospital/Clinic
	10	Recreation center
	11	Passenger terminal
	12	Other
Age of Structure	1	Post 1985 construction
(age)	2	Built between 1980 and 1984
	3	Built between 1970 and 1979
	4	Built between 1960 and 1969
	5	Built between 1950 and 1959
	6	Built between 1940 and 1949
	7	Built before 1940
	9	Unknown
Type of Foundation	1	Basement below ground level

Table 4 Continued

Attribute	Coding	Potential Values
(found)	2	Concrete slab at ground level
	3	Crawl space above ground level
	4	Combination of 1 and 2
	5	Combination of 2 and 3
	6	Combination of 1 and 3
Type of Air Conditioning	1	None
(air)	2	Central air conditioning
	3	One room with window unit
	4	Two or more rooms with window units
Type of Heating System	0	None
(heat)	1	Steam or hot water system
	2	Central heating system
	3	Electric Heat Pump
	4	Other built-in or portable heaters
	5	Floor, wall, or pipeless furnace
	6	Gas or kerosene heaters with flue
	7	Gas or kerosene heaters without flue
	8	Fireplaces, wood or coal stoves

Table 4 Continued

Attribute	Coding	Potential Values
	9	Unknown
Type of Fuel	1	Central base heating plant
(fuel)	2	Natural gas (pipeline)
	3	Gas: bottled, tank, or LP
	4	Electricity only
	5	Fuel oil
	6	Coal
	7	None used
	9	Unknown
Type of Water Used	1	Public water supply system
(water)	2	Private well
Floor Where Sampler Was Placed	0	Basement
(floor)	1	First floor
	2	Second floor or higher
Number of Stories in Structure	1	One
(stories)	2	Two
	3	Three
	4	Four
	5	Five
Sump Pump Present at the Lowest Level	1	Yes
(sump)	2	No

Table 4 Continued

Attribute	Coding	Potential Values
	3	Unknown
Drain Present at the Lowest Level	1	Yes
(drain)	2	No
	3	Unknown

Statistical Analysis

Overview

The frequency distribution of the radon concentrations (percentage basis) was examined for each installation (Appendix A, Figures 1-15). Upon visual inspection, the distributions at each installation closely resembled a log normal distribution. A summary of the mean radon concentrations for each installation studied is given in Table 5. All of the attributes studied (Table 4) are discrete, while radon concentration is a continuous variable. Since discrete variables were used to model a continuous variable, an analysis of variance (ANOVA) procedure was utilized. Furthermore, since the data sets are approximately log-normal, a log transformation of the radon concentration was utilized.

Table 5 Summary of Radon Means

Installation	Radon Mean (pCi/L)	Radon Geometric Mean (pCi/L)	Radon Geometric Standard Deviation (pCi/L)
Grissom	1.48	1.09	2.16
Wright-Patt.	2.30	1.66	2.32
Chanute	1.52	1.17	1.98
Grand Forks	1.18	0.84	2.12
Ellsworth	4.99	3.82	2.21
Peterson	0.97	0.81	1.87
USAF Academy	4.26	2.87	2.52
Bergstrom	1.31	0.97	2.12
Nellis	1.18	0.99	1.83
Edwards	1.05	0.97	1.47
Lajes	2.76	1.79	2.53
Andersen	5.57	2.99	3.29
Yokota	1.49	1.12	2.17
Kadina	2.99	1.71	2.49

Modeling

The statistical software package SAS® (SAS Institute Inc., SAS Circle Box 8000, Cary, NC 27512-8000) PROC GLM was utilized in the modeling phase of this project. The modeling was accomplished using an iterative process. First each attribute in Table 4 was modeled individually in a single factor ANOVA with the log of the radon concentration. Any attribute which had a p-value of greater than 0.05 was deemed statistically insignificant and eliminated from any further consideration. The remaining attributes were entered into a full additive (non-interaction) model. Using the generated ANOVA table, any attribute which had a Type III Sum of Squares p-value greater than 0.05 was eliminated from the model. This step was repeated until no more attributes would fall out of the model. Next, interactions of the remaining variables were entered into the model. Because of the unbalanced nature of the possible ANOVA cells, and a corresponding lack of degrees of freedom, interactions were generally limited to two-way interactions.

Again, an iterative process was used, attempting to maximize R^2, the coefficient of determination, while eliminating statistically insignificant variables (attributes) and variable interactions. When a final model was obtained, it was checked for heteroscedasticity (unequal variances) and normality constraints in the ANOVA assumptions. The final model utilized a SAS® PROC LSMEANS procedure with the standard error option to predict the mean radon concentrations for all attribute combinations. If there were no statistically significant interactions, the PROC LSMEANS procedure determined the mean radon concentrations for each attribute individually. Since a log transformation was utilized, the antilogs of the mean and standard error were taken and recorded as the geometric means and standard deviations.

Trend Analyses

In addition to modeling, trend analyses were performed on each of the 15 data sets using a SAS® PROC MEANS procedure with the SNK (Student-Newman-Keuls) option. These trend analyses analyze radon concentrations among class levels of an attribute when all other factors are ignored.

Comparison

A qualitative comparison was made between the modeling and trend analysis for each of the 15 data sets, including mean radon concentration magnitude comparison.

RESULTS AND DISCUSSION

Grissom AFB

Modeling

The geometric mean of the radon concentration at Grissom AFB is 1.09 pCi/L with a geometric standard deviation of 2.16 pCi/L, based on a sample size of 633. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, and the interaction between age and type of structure (age*struct). The results are shown in the Analysis of Variance (ANOVA) Table , Appendix B, Table B1. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.467. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C1.

Trend Analysis

One story structures had significantly higher radon concentrations than all multi-storied structures. Structures which were built in the 1950s had significantly higher radon concentrations than all other age groups. Buildings with concrete slab foundations had significantly higher radon concentrations than buildings with basements. Buildings with a drain at the lowest level had significantly higher radon concentrations than those without. Buildings with a sump pump at the lowest level had significantly higher radon concentrations than those without. There were no statistically significant differences in radon concentration among class levels of the following attributes: type of structure (single family attached vs. detached) and type of air conditioning. Because the data base contained samples from only one class level of the following attributes, they could not be studied at this installation: type of fuel, type of heating, type of water, and floor where sampler was placed. The computer printouts that support the above statements are included in Appendix D, along with sample SAS programs.

Comparison

The model agrees with the trend analysis in predicting that the combination of attributes which give the highest geometric radon concentration means include structures which were built in the 1950s.

Wright-Patterson AFB

Modeling

The geometric mean of the radon concentration at Wright-Patterson AFB is 1.66 pCi/L with a geometric standard deviation of 2.32 pCi/L, based on a sample size of 2487. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, type of fuel, and type of air conditioning. The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B2. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.293. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C2.

Trend Analysis

Single family homes (detached) and transient living facilities had significantly higher radon concentrations than all other types. Structures which were built in the 1950s had significantly higher radon concentrations than all other age groups. Two story structures had significantly higher radon concentrations than all other types. There were no statistically significant differences in radon concentration among class levels of the following attributes: type of foundation, type of air conditioning, type of heating, type of fuel, and the presence of a sump pump or drain on the lowest level. Because the data base contained samples from only one class level of the following attributes, they could not be studied at this installation: type of water and floor where sampler was placed. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

Since there are no interaction terms in the model, a separate comparison was performed for each attribute. For the attribute type of structure, the model agrees with the trend analysis in predicting that single family detached homes have the highest mean radon concentration. For the attribute age, the model generally agrees with the trend analysis. The model predicts that structures built during the time periods 1980-1984, the 1960s, or the 1950s will have the highest radon concentrations while the trend analysis indicates that structures built in the 1950s have the highest radon concentrations. Since there were no statistically significant differences in the trend analyses for the attributes type of fuel, and type of air conditioning, they could not be compared with the model.

Chanute AFB

Modeling

The geometric mean of the radon concentration at Chanute AFB is 1.17 pCi/L with a geometric standard deviation of 1.98 pCi/L, based on a sample size of 1869. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, type of foundation, and the interaction between age and type of structure (age·struct). The results are shown in the Analysis of Variance (ANOVA) Table , Appendix B, Table B3. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.371. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C3.

Trend Analysis

Single family homes (detached) and child care centers had significantly higher radon concentrations than all other types. Three story structures had significantly higher radon concentrations than all other types. Structures which were built in the 1960s had significantly higher radon concentrations than all other age groups. Homes with basements had significantly higher radon concentrations than homes with concrete slab foundations which had significantly higher radon concentrations than homes with above ground crawl spaces. Buildings with central air conditioning and ones with multiple window air conditioning units had higher radon concentrations than buildings with either no air conditioning or having only one window unit. Buildings with central heating had significantly higher radon concentrations than buildings with portable heaters. Buildings which utilized any combustion fuel had significantly higher radon concentrations than buildings that used only electricity. Surprisingly, buildings without a drain at the lowest level had significantly higher radon concentrations than buildings with a drain. Buildings with a sump pump at the lowest level had significantly higher radon concentrations than those without. Because the data base contained samples from only one class level of the following attributes, they could not be studied at this installation: type of water and floor where sampler was placed. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

The model agrees with the trend analysis in predicting that the combination of attributes which give the highest geometric radon concentration means include structures that have basements. In addition, the model agrees with the trend analysis in predicting that the combination of attributes which give the highest geometric radon concentration mean include single family detached homes. The model, however, does not agree concerning the age attribute. The model predicts that single family detached homes with basements built in the 1950s will have the highest radon concentrations while the trend analysis indicates that structures built in the 1960s have the highest radon concentrations.

Grand Forks AFB

Modeling

The geometric mean of the radon concentration at Grand Forks AFB is 0.84 pCi/L with a geometric standard deviation of 2.12 pCi/L, based on a sample size of 2520. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, number of stories, the interaction between the number of stories and the presence of a sump pump at the lowest level (stories*sump), and the interaction between age and the presence of a sump pump at the lowest level (age*sump). The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B4. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.299. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C4.

Trend Analysis

One story structures had significantly higher radon concentrations than all multi-storied structures. Buildings with either central heating or steam/hot water heating had significantly higher radon concentrations than buildings with portable heaters. Buildings which utilized bottled gas had significantly lower radon concentrations than any other fuel source. Buildings without a sump pump at the lowest level had significantly higher radon concentrations than those with. There were no statistically significant differences in radon concentration among class levels of the following attributes: type of structure, age, type of foundation, and type of air conditioning. Because the data base contained samples from only one class level of the following attributes, they could not be studied at this installation: type of water and floor where sampler was placed. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

Since there were no significant differences in the trend analysis for the attributes age and type of structure, a comparison could not be accomplished.

Ellsworth AFB

Modeling

The geometric mean of the radon concentration at Ellsworth AFB is 3.82 pCi/L with a geometric standard deviation of 2.21 pCi/L, based on a sample size of 1398. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, type of foundation, type of heating, and the presence of a drain at the lowest level. The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B5. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.572. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C5.

Trend Analysis

Single family homes (both attached and detached) had significantly higher radon concentrations than all other types. Structures which were built in the 1960s had significantly higher radon concentrations than all other age groups. Homes with basements had significantly higher radon concentrations than all other foundation types. Buildings with central air conditioning had significantly lower radon concentrations than all other air conditioning types. Buildings with steam or hot water heating systems had significantly higher radon concentrations than buildings with central heating. Surprisingly, buildings with a drain at the lowest level had significantly lower radon concentrations than those without. There were no statistically significant differences in radon concentration among class levels of the following attributes: number of stories, type of fuel, and the presence of a sump pump at the lowest level. Because the data base contained samples from only one class level of the following attributes, they could not be studied at this installation: type of water and floor where sampler was placed. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

Since there are no interaction terms in the model, a separate comparison is performed for each attribute. For the attribute type of structure, the model agrees with the trend analysis in predicting that single family homes (both attached and detached) have the highest mean radon concentrations. For the attribute type of heating system, the model agrees with the trend analysis in predicting that structures with central heating have lower mean radon concentrations than structures with steam/hot water heating systems. For the attribute drain present at the lowest level, the model agrees with the trend analysis in predicting structures with drains at the lowest level have lower mean radon concentrations than those without. For the attribute type of foundation, the model predicts that buildings with concrete slab foundations will have the highest mean radon concentrations, while the trend analysis indicates that buildings with basements have the highest mean radon concentrations. For the attribute age, the model predicts that structures built since 1985 will have the highest mean radon concentrations, while the trend analysis indicates that structures built in the 1960s have the highest mean radon concentrations.

Peterson AFB

Modeling

The geometric mean of the radon concentration at Peterson AFB is 0.81 pCi/L with a geometric standard deviation of 1.87 pCi/L, based on a sample size of 684. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, type of heat, and the interaction between age and type of structure (age*struct). The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B ,Table B6. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.627. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C6.

Trend Analysis

Structures which were built since 1985 had significantly higher radon concentrations than those built in the 1950s, which had significantly higher radon concentrations than those built in the 1960s, which had significantly higher radon concentrations than those built in the time period 1980-1984, which had significantly higher radon concentrations than those built in the 1970s. Buildings with combination basements and concrete slab foundations as well as buildings with combination concrete slab and crawl space foundations had significantly higher radon concentrations than all other foundation types. Buildings with one window unit air conditioning had significantly lower radon concentrations than all other air conditioning types. Buildings which used bottled gas had radon concentrations which were significantly less than all other fuels. There were no statistically significant differences in radon concentration among class levels of the following attributes: type of structure, number of stories, type of heating, and the presence of a sump pump or a drain at the lowest level. Because the data base contained samples from only one class level of the following attributes, they could not be studied at this installation: type of water and floor where sampler was placed. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

The model did not agree with the trend analysis, since there were no discernible patterns in the model, while there were several in the trend analysis.

USAF Academy

Modeling

The geometric mean of the radon concentration at the USAF Academy is 2.87 pCi/L with a geometric standard deviation of 2.52 pCi/L, based on a sample size of 1207. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, and the interaction between type of structure and type of foundation (struct*found). The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B7. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.191. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C7.

Trend Analysis

Buildings with basements had significantly higher radon concentrations than all other foundation types. Buildings with a drain at the lowest level had significantly lower radon concentrations than those without. Buildings with a sump pump at the lowest level had significantly higher radon concentrations than those without. There were no statistically significant differences in radon concentration among class levels of the following attributes: type of structure, number of stories, age, type of air conditioning, type of heating, and type of fuel. Because the data base contained samples from only one class level of the following attributes, they could not be studied at this installation: type of water and floor where sampler was placed. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

In general the model agrees with the trend analysis in predicting that structures with basements have higher mean radon concentrations. A noticeable exception is the category child care centers with slab foundations which has the highest predicted mean radon concentration.

Bergstrom AFB

Modeling

The geometric mean of the radon concentration at Bergstrom AFB is 0.97 pCi/L with a geometric standard deviation of 2.12 pCi/L, based on a sample size of 941. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, number of stories, and the interaction between the number of stories and the type of structure (stories*struct). The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B8. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.443. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C8.

Trend Analysis

Single family homes (detached) had significantly higher radon concentrations than all other structure types. One story structures had significantly higher radon concentrations than all multi-storied structures. Structures which were built in the 1960s had significantly higher radon concentrations than all other age groups. Buildings with concrete slab foundations had significantly higher radon concentrations than all other foundation types. Buildings with central heating had significantly higher radon concentrations than those with steam or hot water heating systems. There were no statistically significant differences in radon concentration among class levels of the following attributes: type of air conditioning, and type of fuel. Because the data base contained samples from only one class level of the following attributes, they could not be studied at this installation: type of water, floor where sampler was placed, and the presence of a sump pump or a drain at the lowest level. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

The model agrees with trend analysis in predicting that single family detached homes have the highest mean radon concentrations. In addition, the model agrees with trend analysis in predicting that single story structures have the highest mean radon concentrations. The model predicts that single story, single family detached homes built in the 1950s have higher mean radon concentrations than the same type of homes built in the 1960s, while the trend analysis indicates that structures built in the 1960s have the highest mean radon concentrations.

Nellis AFB

Modeling

The geometric mean of the radon concentration at Nellis AFB is 0.99 pCi/L with a geometric standard deviation of 1.83 pCi/L, based on a sample size of 1723. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, and the interaction between age and type of structure (age*struct). The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B9. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.438. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C9.

Trend Analysis

Single family homes (detached) had significantly higher radon concentrations than all other structure types. One story structures had significantly higher radon concentrations than all multi-storied structures. Structures which were built in the 1950s had significantly higher radon concentrations than all other age groups. Buildings with concrete slab foundations had significantly higher radon concentrations than buildings with basements. Buildings which utilized natural gas had significantly higher radon concentrations than buildings which only utilized electricity. Because the data base contained samples from only one class level of the following attributes, they could not be studied at this installation: type of water, floor where sampler was placed, type of air conditioning, type of heating, and the presence of a sump pump or a drain at the lowest level. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

The model agrees with the trend analysis in predicting that single family detached homes built in the 1950s and 1960s have the highest mean radon concentrations.

Edwards AFB

Modeling

The geometric mean of the radon concentration at Edwards AFB is 0.97 pCi/L with a geometric standard deviation of 1.47 pCi/L, based on a sample size of 2342. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, number of stories, type of foundation, and type of fuel. The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B10. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.405. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C10.

Trend Analysis

Hospitals/Clinics had significantly lower radon concentrations than all other structures. One story structures had significantly higher radon concentrations than multi-storied structures. Structures which were built in the 1940s had significantly higher radon concentrations than all other age groups. Buildings with either a crawl space or concrete slab foundation had significantly higher radon concentrations than buildings with basements or combination basements and concrete slab foundations. Buildings with no air conditioning had significantly higher radon concentrations than those with central air conditioning. Buildings with either central heating or steam/hot water heating systems had significantly higher radon concentrations than buildings with portable heaters. Buildings which utilized bottled gas had significantly higher radon concentrations than buildings which utilized natural gas from a pipeline. Because the data base contained samples from only one class level of the following attributes, they could not be studied at this installation: type of water, floor where sampler was placed, and the presence of a sump pump or a drain at the lowest level. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

Since there are no interaction terms in the model, a separate comparison is performed for each attribute. For the attribute type of structure, the model agrees with the trend analysis in predicting that hospitals/clinics have the lowest radon mean concentrations. For the attribute type of foundation, the model agrees with the trend analysis in predicting structures with crawl spaces have the highest mean radon concentrations, however, the model predicts that structures with slab foundations will have the lowest mean radon concentrations, whereas the trend analysis indicates they have the higher mean radon concentrations. The model predicts that buildings using pipeline natural gas will have higher mean radon concentrations than buildings using bottled gas, while the trend analysis indicates the exact opposite. Due to the unbalanced nature of the data base, the model could not provide mean radon concentration estimates for the attributes age and number of stories.

Aviano AB

Modeling

The geometric mean of the radon concentration at Aviano AB is 5.34 pCi/L with a geometric standard deviation of 2.48 pCi/L, based on a sample size of 373. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, the interaction between age and type of structure (age*struct), and the interaction between age and the number of stories (age*stories). The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B11. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.466. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C11.

Trend Analysis

Radon concentrations measured on the first floor were significantly higher than radon concentrations measured on the second floor. There were no statistically significant differences in radon concentration among class levels of the following attributes: type of structure, age, number of stories, type of foundation, type of air conditioning, type of fuel, and the presence of a sump pump or a drain at the lowest level. Because the data base contained samples from only one class level of the attribute type of water, it could not be studied at this installation. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

The model agreed with the trend analysis in that there are no distinct patterns of attribute combinations which result in higher mean radon concentrations.

Lajes AB

Modeling

The geometric mean of the radon concentration at Lajes AB is 1.79 pCi/L with a geometric standard deviation of 2.53 pCi/L, based on a sample size of 745. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, type of foundation, and type of air conditioning. The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B12. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.321. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C12.

Trend Analysis

Schools had significantly higher radon concentrations than all other structures. One and two story structures had significantly higher radon concentrations than three story structures. Buildings with combination concrete slab and crawl space foundations had significantly higher radon concentrations than buildings with combination basement and concrete slab foundations, which had significantly higher radon concentrations than buildings with either above ground crawl spaces or concrete slab foundations. Buildings with one window air conditioning unit had significantly lower radon concentrations than those with either central air conditioning or no air conditioning. Radon concentrations measured on the second floor were surprisingly significantly higher than radon concentrations measured on the first floor. There were no statistically significant differences in radon concentration among class levels of the following attributes: age, type of heating, type of fuel, type of water, and presence of a sump pump or a drain at the lowest level. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

Since there are no interaction terms in the model, a separate comparison was performed for each attribute. For the attribute type of structure, the model agrees with the trend analysis in predicting that schools have the highest mean radon concentration. For the attribute type of foundation, the model agrees with the trend analysis in predicting that structures with a combination crawl space and concrete slab foundation have the highest mean radon concentration. For the attribute type of air conditioning, the model agrees with the trend analysis in predicting that structures with one window unit air conditioner have the lowest mean radon concentration. Since there were no significant differences in the trend analyses for the attribute age, it could not be compared with the model.

Andersen AFB

Modeling

The geometric mean of the radon concentration at Andersen AFB is 2.99 pCi/L with a geometric standard deviation of 3.29 pCi/L, based on a sample size of 1795. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, and the interaction between age and type of structure (age*struct). The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B13. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.402. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C13.

Trend Analysis

Dormitories and transient living facilities had significantly lower radon concentrations than all other structures. One story structures had significantly higher radon concentrations than two story structures, which had significantly higher radon concentrations than three story structures. Structures which were built in the 1940s had significantly higher radon concentrations than all other age groups. Buildings with a drain at the lowest level had significantly higher radon concentrations than those without. Radon concentrations measured on the first floor were significantly higher than radon concentrations measured on the second floor. There were no statistically significant differences in radon concentration among class levels of the following attributes: type of foundation and type fuel. Because the data base contained samples from only one class level of the following attributes, they could not be studied at this installation: type of water, type of air conditioning, type of heating, and the presence of a sump pump on the lowest level. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

The model agrees with the trend analysis in predicting that dormitories and temporary living facilities have the lowest mean radon concentrations. The model agrees with the trend analysis in predicting that structures built in the 1940s have the highest mean radon concentrations.

Yokota AB

Modeling

The geometric mean of the radon concentration at Yokota AB is 1.12 pCi/L with a geometric standard deviation of 2.17 pCi/L, based on a sample size of 1431. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, number of stories, type of foundation, type of fuel, and type of heating. The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B14. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.266. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C14.

Trend Analysis

Single family attached homes had significantly higher radon concentrations than single family detached homes. Buildings with one window air conditioning unit had significantly lower radon concentrations than all other air conditioning types. Buildings with a drain at the lowest level had significantly lower radon concentrations than buildings without a drain. Buildings with a sump pump at the lowest level had significantly lower radon concentrations than those without. There were no statistically significant differences in radon concentration among class levels of the following attributes: number of stories, age, type of foundation, type of heating, type of fuel, and floor sampled. Because the data base contained samples from only one class level of the attribute type of water, it could not be studied at this installation. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

Since there are no interaction terms in the model, a separate comparison was performed for each attribute. For the attribute type of structure, the model agrees with the trend analysis in predicting that single family attached homes have higher mean radon concentrations than single family detached homes. Since there were no statistically significant differences in the trend analyses for the attributes age, type of foundation, number of stories, type of fuel, and type of heating they could not be compared with the model.

Kadina AB

Modeling

The geometric mean of the radon concentration at Kadina AB is 1.71 pCi/L with a geometric standard deviation of 2.49 pCi/L, based on a sample size of 5801. From the iterative process described earlier, the following attributes were found to be statistically significant when related to radon concentration: age, type of structure, and the interaction between age and type of structure (age*struct). The results are shown in the Analysis of Variance (ANOVA) Table, Appendix B, Table B15. All other variables from Table 4 were found to be statistically insignificant and were eliminated from the model. The model has an R^2 of 0.275. The predictions of the model for various combinations of the attributes are included in Appendix C, Table C15.

Trend Analysis

Buildings with central air conditioning had the highest radon concentrations. Buildings with portable heaters had significantly lower radon concentrations than all other heating methods. Radon concentrations measured on the first floor were significantly higher than radon concentrations measured on the second floor. Buildings with a sump pump at the lowest level had significantly lower radon concentrations than those without. There were no statistically significant differences in radon concentration among class levels of the following attributes: type of structure, age, number of stories, type of foundation, type of fuel, and presence of a drain on the lowest level. Because the data base contained samples from only one class level of the attribute type of water, it could not be studied at this installation. The computer programs used to support the above statements were nearly identical to those utilized for Grissom AFB, but the actual printouts are not shown.

Comparison

Since there were no significant differences in the trend analysis for the attributes age and type of structure, a comparison could not be accomplished.

Overall Results and Discussion

Modeling

A summary of the models developed for the 15 installations is found in Table 5. From this Table, it is clear that the major attributes in explaining radon concentration are age, type of structure, and the interaction between them. Minor attributes include type of foundation, type of fuel, number of stories, type of heating, and floor where sampler was placed. In general the following attributes are not related to radon concentration: type of air conditioning, type of water, and the presence of a sump pump or a drain at the lowest level.

Table 6 Model Summary

Installation	Statistically Significant Attributes	R^2
Grissom	age age*struct	0.467
Wright-Patterson	age struct fuel air	0.293
Chanute	age struct age*struct found	0.371
Grand Forks	age struct stories age*sump stories*sump	0.299
Ellsworth	age struct found heat drain	0.572
Peterson	age struct age*struct heat	0.627
Academy	age struct*found	0.191
Bergstrom	age struct stories struct*stories	0.443
Nellis	age struct age*struct	0.438
Edwards	age struct stories found fuel	0.405
Aviano	age struct age*struct age*stories	0.466
Lajes	age struct found air	0.321
Andersen	age struct age*struct	0.402
Yokota	age struct stories found fuel heat	0.266
Kadina	age struct age*struct	0.275

Trend Analyses

A summary of the trend analyses performed for the 15 installations is found in Table 6. In general, the following attributes tend to yield the highest radon concentrations: single family homes, single story structures, and structures built during the 1940s, 1950s, and 1960s. All the other attributes do not have a distinct trend among the 15 installations studied.

Table 7 Trend Analysis Summary

Installation	Significant Results	Attributes with no significant difference	Attributes not studied
Grissom	one story bldgs highest, bldgs built in the 50s highest, slabs greater than basements, sump pump highest, drain highest	struct, air	fuel, heat, water, floor
Wright-Patterson	single family detached homes and child care centers highest, bldgs built in the 50s highest, two story bldgs highest	found, air, heat, fuel, sump, drain	water, floor
Chanute	single family detached homes and child care centers highest, 3 story bldgs highest, bldgs with basements highest, central air highest, central heating highest, electric only lowest, drain lowest, sump pump highest		water, floor
Grand Forks	one story bldgs highest, central heating and steam/hot water heating highest, bottled gas lowest, sump pump lowest	age, struct, found, air	water, floor
Ellsworth	single family homes highest, bldgs built in the 60s highest, bldgs with basements highest, central air lowest, steam/hot water heat greater than central heat, drain lowest	stories, fuel, sump	water, floor
Peterson	bldgs built since 1985 greater than bldgs built in the 50s, bldgs with basement/slab combos and slab/crawl space combos highest, one window air unit lowest, bottled gas highest	struct, stories, heat, sump, drain	water, floor
Academy	bldgs with basements highest, drain lowest, sump pump highest	struct, age, stories, fuel, air, heat	water, floor
Bergstrom	single family detached homes highest, one story bldgs highest, bldgs built in the 60s highest, slab found. bldgs highest, central heat greater than steam heat	air, fuel	sump, drain, water, floor

Table 7 Continued

Installation	Significant Results	Attributes with no significant difference	Attributes not studied
Nellis	single family detached homes highest, one story bldgs highest, bldgs built in the 50s highest, slabs greater than basements, natural gas greater than electricity		air, heat, water, floor, sump, drain
Edwards	hospital/clinics lowest, one story bldgs highest, bldgs built in the 40s highest, crawl spaces or slabs higher than basements or basement/slab combos, no air conditioning higher than central air, portable heaters only lowest, bottled gas higher than pipeline gas		water, floor, sump, drain
Aviano	first floor higher than second floor	age, struct, stories, found, air, heat, fuel, sump, drain	water
Lajes	schools highest, one and two story bldgs higher than three story bldgs, slab/crawl space combo highest, one window air unit lowest, second floor higher than first floor	age, heat, water, fuel, sump, drain	
Andersen	dorms and transient living facilities lowest, one story bldgs highest, bldgs built in the 40s highest, drain highest, first floor higher than second floor	found, fuel	air, water, sump, heat
Yokota	single family attached homes higher than single family detached homes, one window A/C unit lowest, drain lowest, sump lowest	stories, age, found, heat, fuel, floor	water
Kadina	central air highest, portable heaters lowest, first floor higher than second floor, sump lowest	struct, age, stories, found, fuel, drain	water

Comparison

Modeling indicated that age and type of structure are the major attributes in explaining the variation of radon concentration, however, these attributes in the trend analyses did not have any significant difference among the class members in six out of 15 cases (see Table 6). At first glance, this may seem to be a contradiction, but can easily be explained as follows. When considered individually, each attribute may not have any statistically significant differences, however, when considered collectively, including interactions, these attributes are statistically significant.

R-squared

R-squared, the coefficient of determination, represents the fraction of the sample variation that is attributable to the regression model. In these studies R^2 ranged from 0.191 to 0.627, which is much better than values obtained by Liu et al., and Bierman and O'Neill (0.268 and 0.0049 - 0.253, respectively), but still less than ideal and rather poor for predictive uses. (Li 90, Bi 91) Since all of the coefficient of determinations were less than 0.8, this indicates that other factors, for example the underlying geology, may be more important than the attributes examined in the study.

Unbalanced ANOVAs

Because these data bases were not specifically designed for statistical analyses, some problems arose. The major problem was unbalanced ANOVAs. There were 11 different attributes studied, and each attribute had a minimum of three classes (except type of water). Therefore over 100,000 possible combinations of the attributes existed. Ideally when performing an ANOVA, it is desirable to have an equal number of samples for each possible combination, i.e., a balanced ANOVA. Since this was clearly not the case, unbalanced ANOVAs were utilized. The unbalanced ANOVAs *resulted in loss of degrees of freedom* for some of the interaction terms, and it also may account for the large geometric standard deviations for the cells with only a few members. Additionally, the unbalanced ANOVAs may account for the relatively large magnitude differences in the radon concentrations between the models and the actual data for some of the installations.

SUMMARY AND CONCLUSIONS

Overview

A statistical analysis was conducted of the detailed assessment phase of the United States Air Force Radon Assessment and Mitigation Program (RAMP) for 15 installations worldwide. The purpose of the study was to attempt to correlate radon concentrations with various building attributes.

Trend Analyses

Considering the attribute, type of structure, this study agrees with Liu et al., in concluding that single family homes have the highest radon concentrations. Some of the trend analyses conducted in this study agree with Cohen, that homes with basements have the highest radon concentrations, although about the same number agree with Liu et al., that homes with slab foundations have the highest radon concentrations. (Li 90, Co 86) This study agrees with both Harrell and Kumar, and Bierman and O'Neill, that both the presence of a drain or a sump pump are not statistically related to radon concentrations. This study agrees with Cohen that 30-39-y old homes have the highest radon concentrations, but did not agree with Liu et al., and Cohen and Gromicko, whose studies indicate that homes less than 10 years old have the highest radon concentrations. (Co 86, Co 91, Li 90) This study agrees with many that indicate that sampling on lower levels in a building will give higher radon concentrations than on higher levels. (Bi 91, Co 88, Co 91)

The trend analyses in this study do not agree with Cohen concerning the number of stories. This study indicates that single story structures have the highest radon concentrations, whereas Cohen states that two and three story structures have the highest radon concentrations. This disagreement, however, is most likely explained by the fact that Cohen considered one-story homes with basements to be two-story structures, while this study considers them to be single story structures with basements. This study also does not agree with Bierman and O'Neill concerning air conditioning. This study indicates inconclusive results, while Bierman and O'Neill state that buildings with central air conditioning have lower radon concentrations. (Co 86, Bi 91)

Modeling

In general the modeling efforts in this study were more successful than Liu et al., and Bierman and O'Neill, since the R^2 values from this study are better. This can probably be explained by the fact that many samples were taken in a relatively small area, and that housing is fairly uniform at Department of Defense installations, where many of the units are built from the same plan and the same time frame. However, the R^2 values are still too poor to be used for predictive uses.

The attributes age, type of structure, and their interaction are correlated with radon concentrations, and generally can account for about one-fourth to one-half the variation of radon concentrations in the model, which indicates that other factors, such as the underlying geology or construction materials, may be more important than the attributes examined in this study. The bottom line is that the building attributes identified in this study are related to radon concentration but cannot alone be used to predict the radon concentration in a structure.

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APPENDICES

Appendix A

Radon Concentration Frequency Distributions

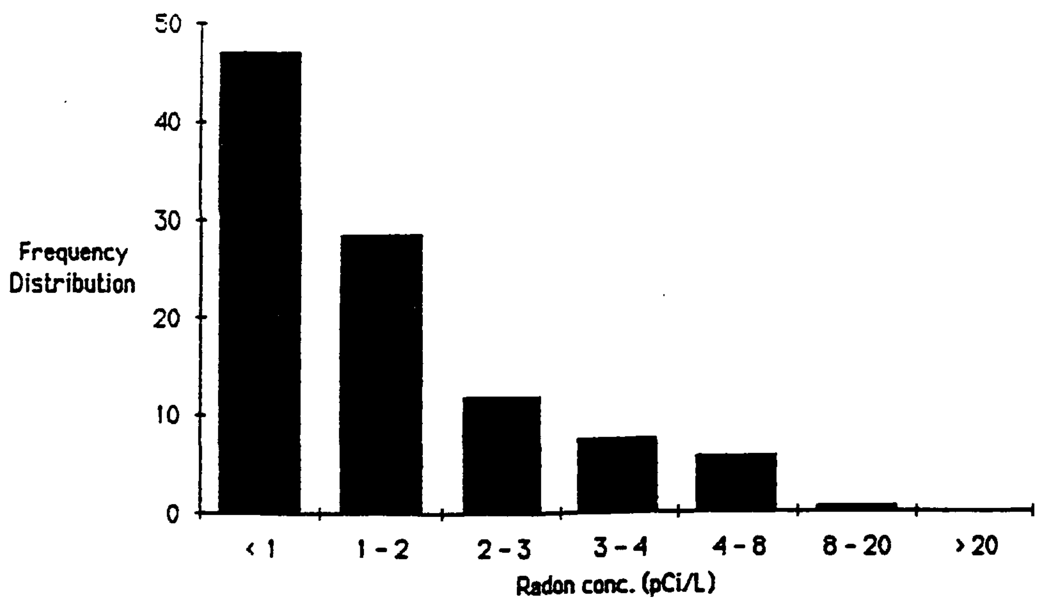

Figure 1 Grissom AFB Radon Distribution

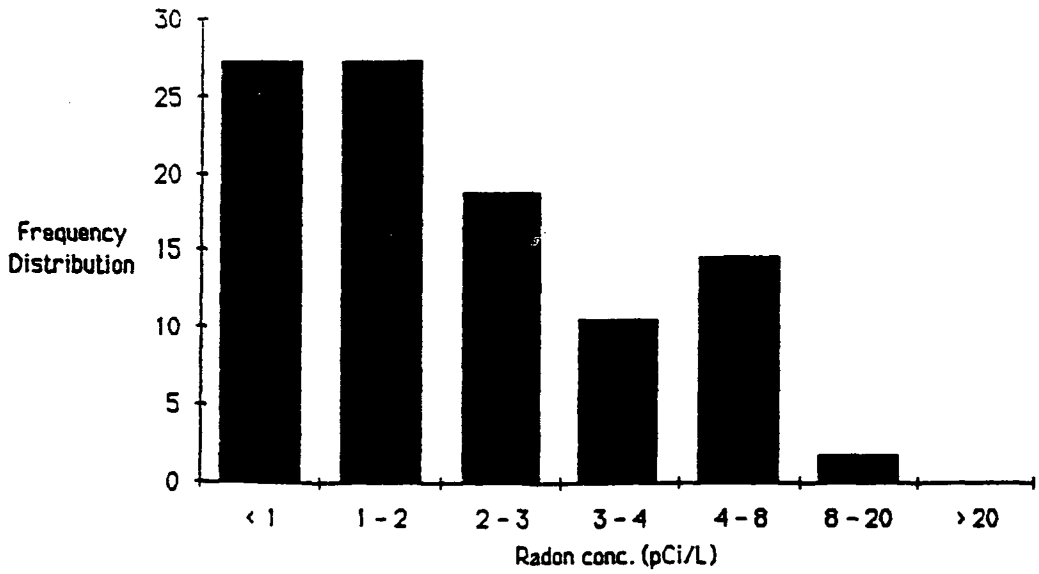

Figure 2 Wright-Patterson AFB Radon Distribution

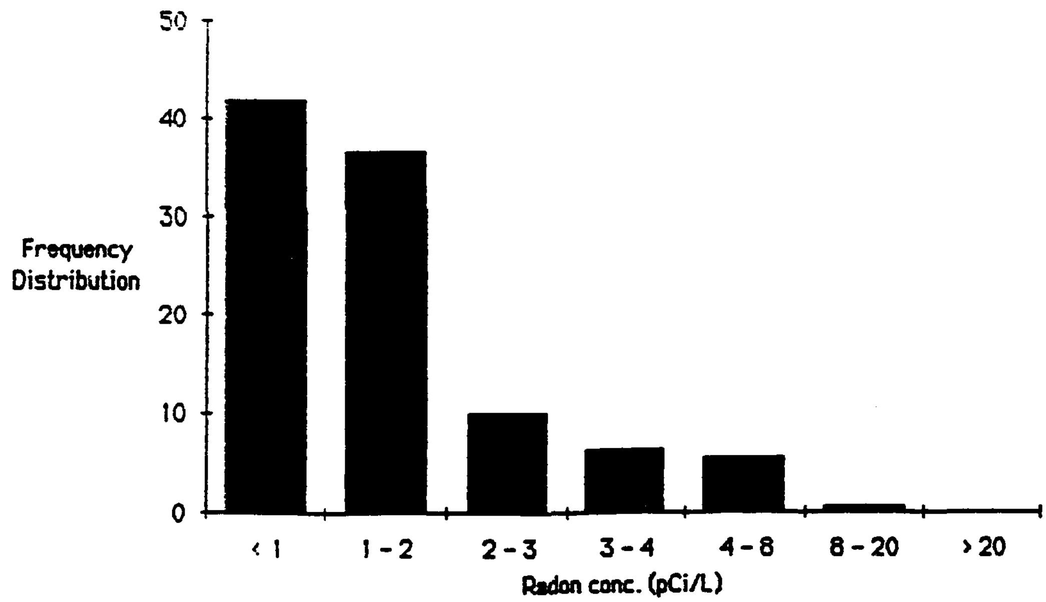

Figure 3 Chanute AFB Radon Distribution

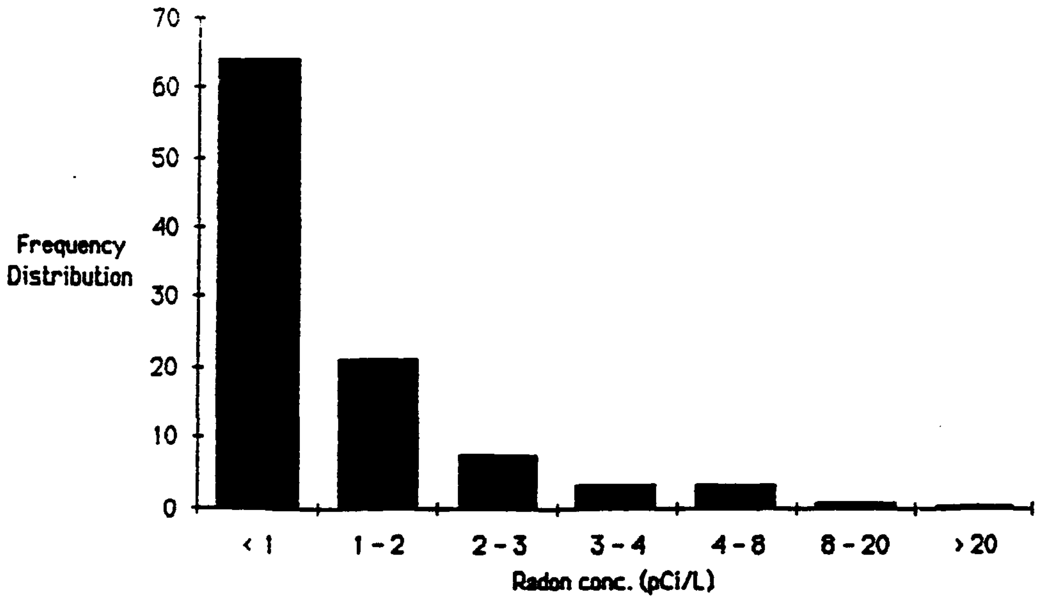

Figure 4 Grand Forks AFB Radon Distribution

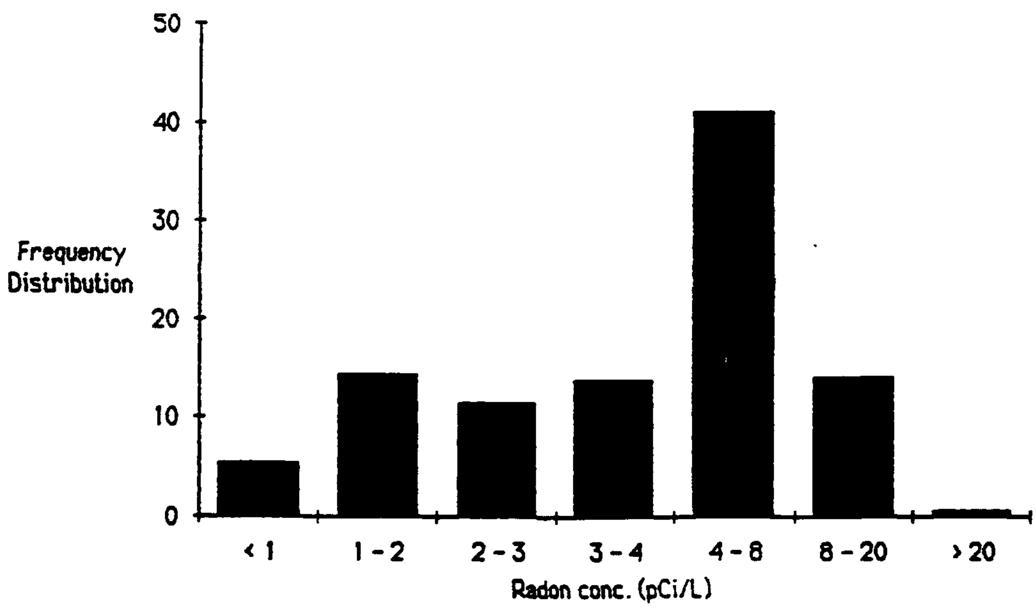

Figure 5 Ellsworth AFB Radon Distribution

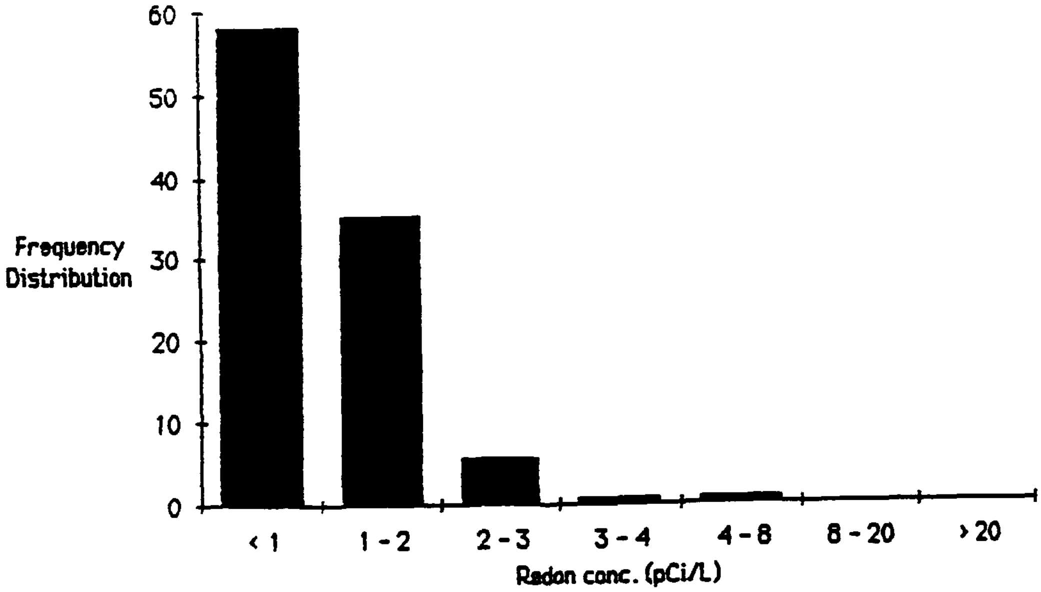

Figure 6 Peterson AFB Radon Distribution

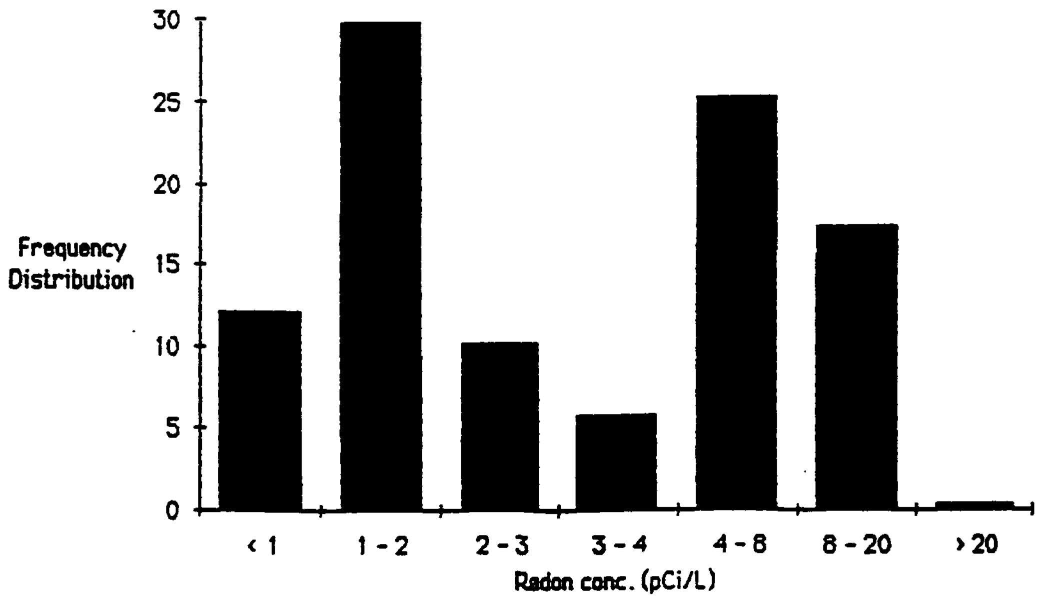

Figure 7 USAF Academy Radon Distribution

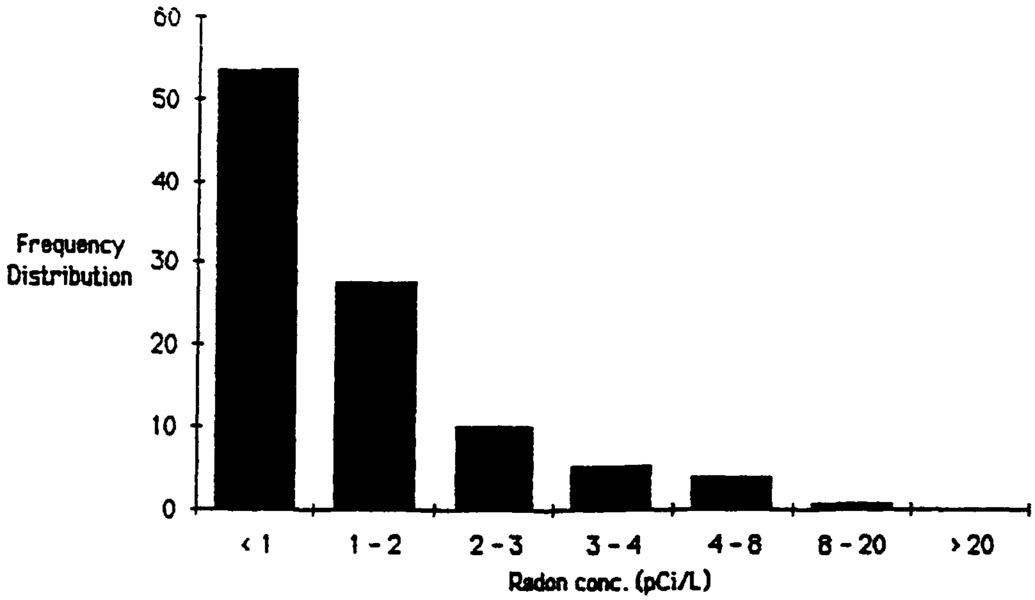

Figure 8 Bergstrom AFB Radon Distribution

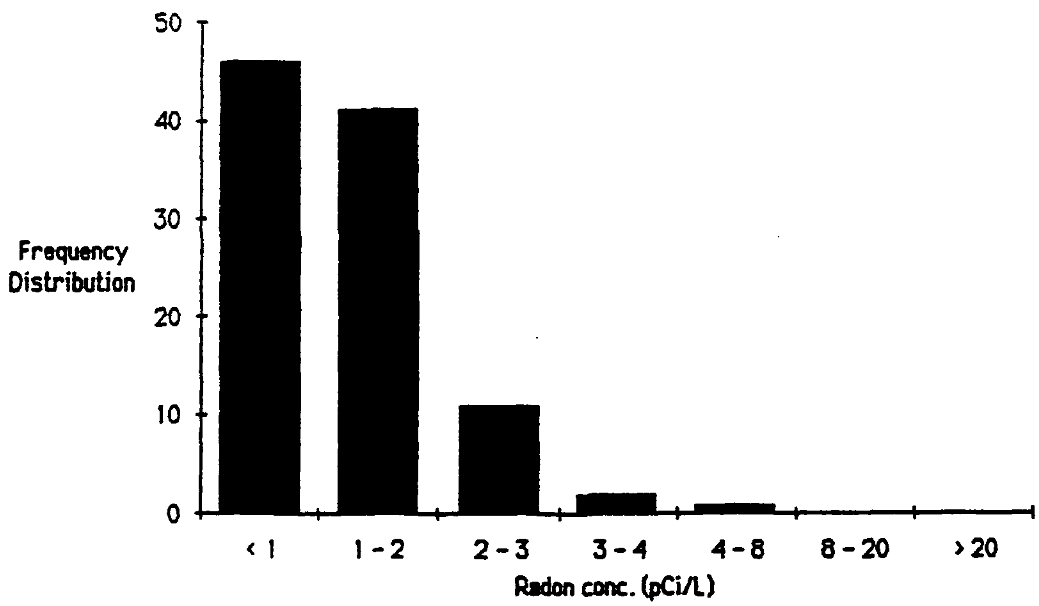

Figure 9 Nellis AFB Radon Distribution

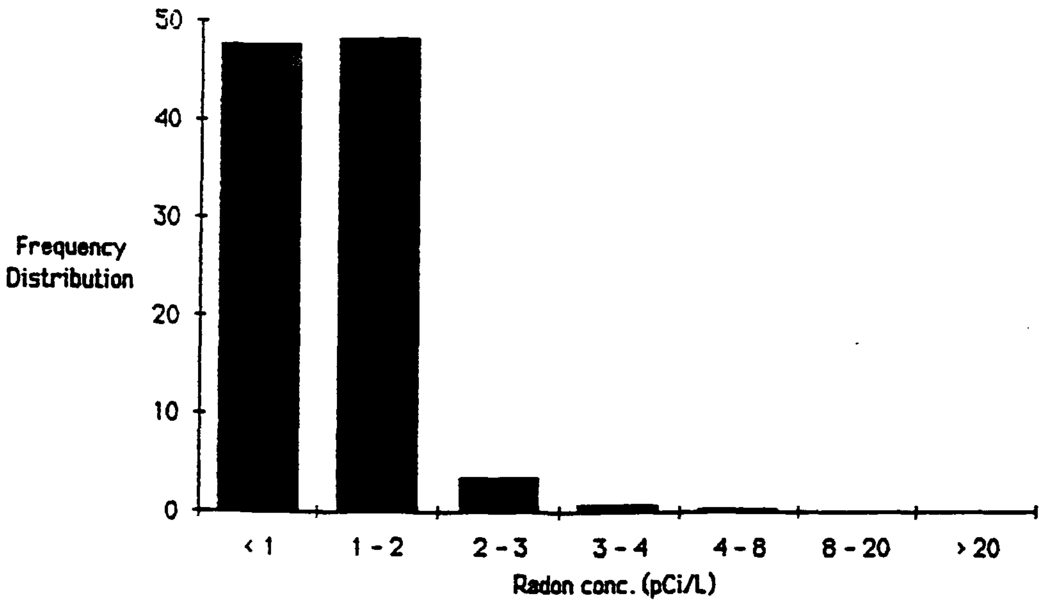

Figure 10 Edwards AFB Radon Distribution

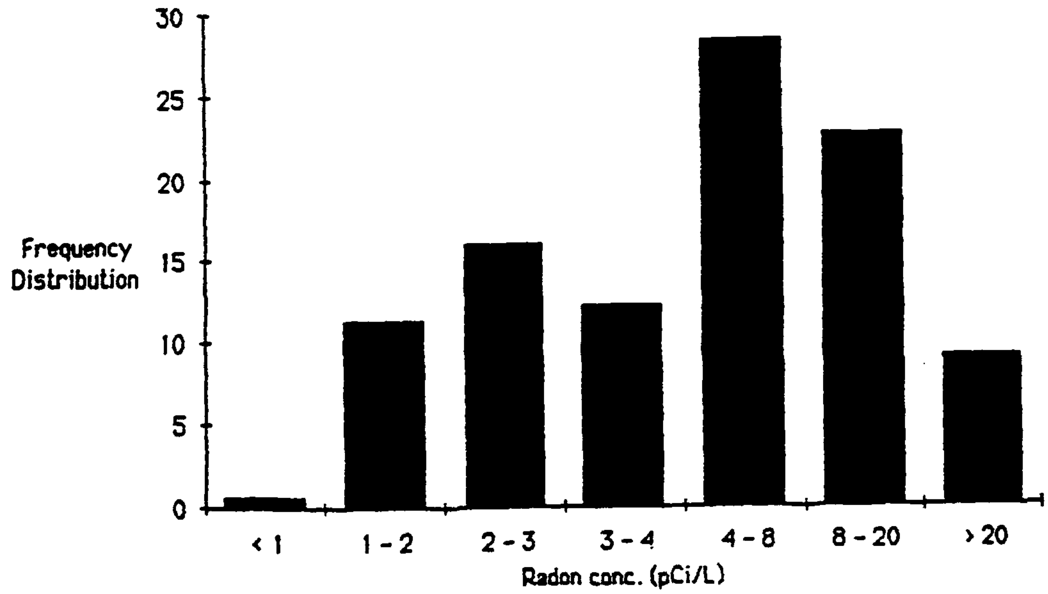

Figure 11 Aviano AB Radon Distribution

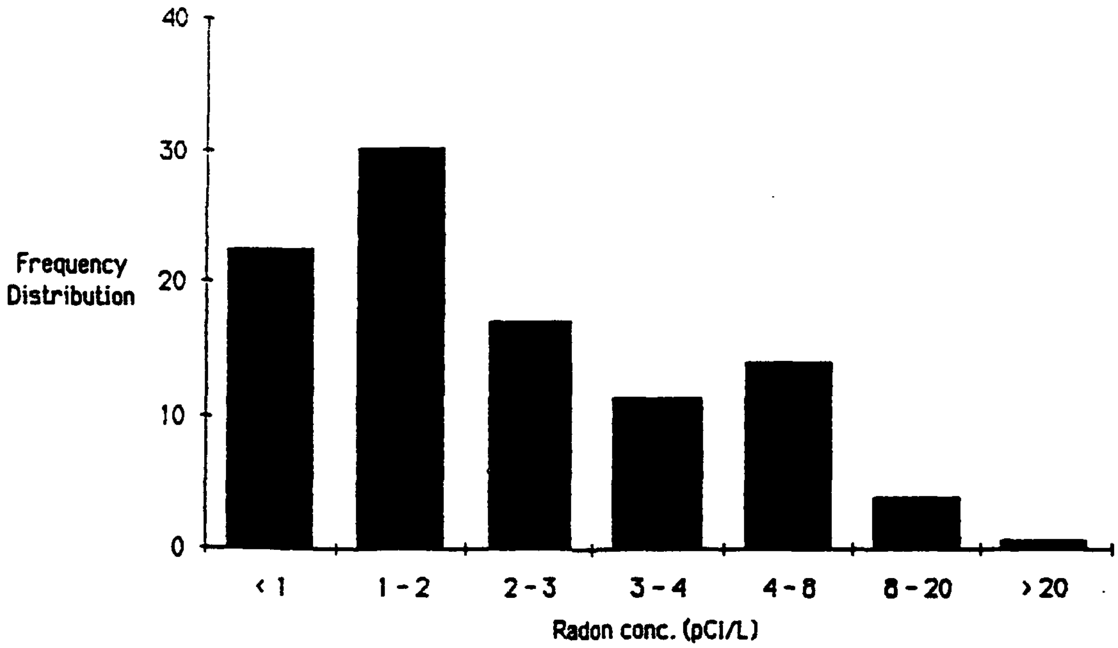

Figure 12 Lajes AB Radon Distribution

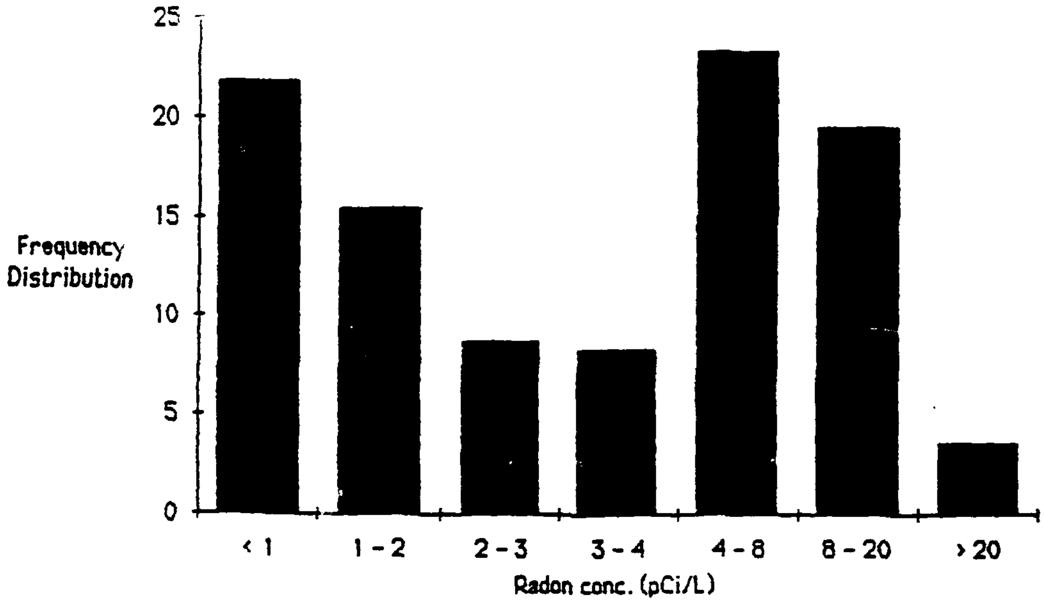

Figure 13 Andersen AFB Radon Distribution

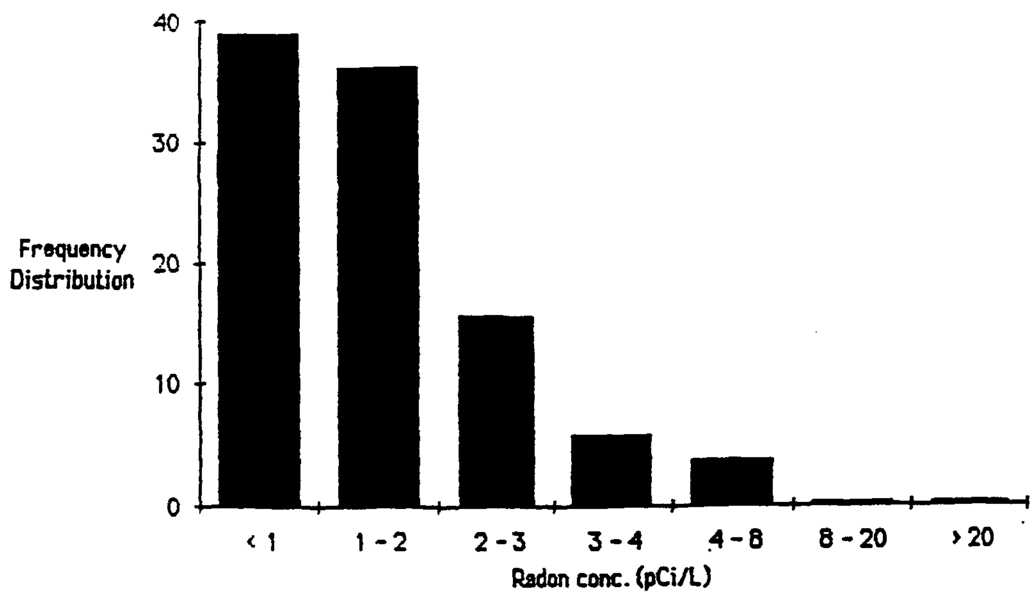

Figure 14 Yokota AB Radon Distribution

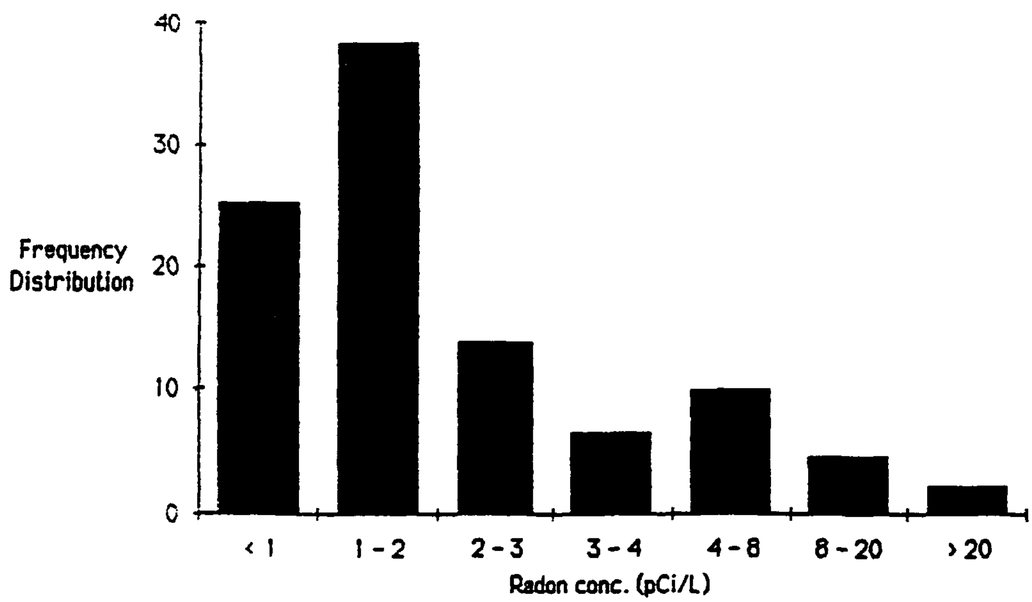

Figure 15 Kadina AB Radon Distribution

Appendix B

ANOVA Tables

Table B1 ANOVA Table for Grissom AFB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	175.73090101	21.96636263	68.24	0.0001
Error	624	200.87736326	0.32191885		
Corrected Total	632	376.60826427			

	R-Square	C.V.	Root MSE	RADLOG Mean
	0.466615	637.4621	0.56737893	0.0890059

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	3	164.28341666	54.76113889	170.11	0.0001
STRUCT	3	3.43025892	1.14341964	3.55	0.0143
AGE*STRUCT	2	8.01722542	4.00861271	12.45	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	3	114.91713594	38.30571198	118.99	0.0001
STRUCT	3	0.40360870	0.13453623	0.42	0.7402
AGE*STRUCT	2	8.01722542	4.00861271	12.45	0.0001

Table B2 ANOVA Table for Wright-Patterson AFB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	18	508.85994780	28.25888598	56.72	0.0001
Error	2468	1229.52033671	0.49818490		
Corrected Total	2486	1738.18028431			

R-Square	C.V.	Root MSE	RADLOG Mean
0.292639	133.0437	0.70582215	0.53051904

Source	DF	Type I SS	Mean Square	F Value	Pr > F
STRUCT	6	154.25977415	25.70996236	51.61	0.0001
FUEL	4	78.98958689	19.74739672	39.64	0.0001
AGE	5	261.88523742	52.37704748	105.14	0.0001
AIR	3	13.52534914	4.50844971	9.05	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
STRUCT	6	178.94020074	29.82336679	59.86	0.0001
FUEL	4	262.94362743	65.73590686	131.95	0.0001
AGE	5	272.02705437	54.40541087	109.21	0.0001
AIR	3	13.52534914	4.50844971	9.05	0.0001

Table B3 ANOVA Table for Chanute AFB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	325.30306462	17.12121393	57.35	0.0001
Error	1849	551.95730595	0.29851666		
Corrected Total	1868	877.26037057			

R-Square	C.V.	Root MSE	RADLOG Mean
0.370817	340.5492	0.54636678	0.16043695

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	5	59.62592261	11.92518452	39.95	0.0001
STRUCT	7	59.55441608	8.50777373	28.50	0.0001
AGE*STRUCT	3	3.50281208	1.16760403	3.91	0.0085
FOUND	2	201.85418249	100.92709125	338.10	0.0001
AGE*FOUND	1	0.49432961	0.49432961	1.66	0.1983
STRUCT*FOUND	1	0.27140174	0.27140174	0.91	0.3405
AGE*STRUCT*FOUND	0	0.00000000	.	.	.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	4	13.11883150	3.27970788	10.99	0.0001
STRUCT	7	16.51178431	2.35882633	7.90	0.0001
AGE*STRUCT	1	1.82102885	1.82102885	6.10	0.0136
FOUND	2	6.93199774	3.46599887	11.61	0.0001
AGE*FOUND	1	0.49166198	0.49166198	1.65	0.1995
STRUCT*FOUND	1	0.27140174	0.27140174	0.91	0.3405
AGE*STRUCT*FOUND	0	0.00000000	.	.	.

Table B4 ANOVA Table for Grand Forks AFB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	24	424.15505632	17.67312735	44.43	0.0001
Error	2495	992.45854204	0.39777897		
Corrected Total	2519	1416.61359835			

R-Square	C.V.	Root MSE	RADLOG Mean
0.299415	-363.0782	0.63069721	-0.17370837

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	2	8.06314478	4.03157239	10.14	0.0001
STRUCT	6	65.79267333	10.96544556	27.57	0.0001
AGE*STRUCT	4	19.09756730	4.77439183	12.00	0.0001
STORIES	2	75.32240751	37.66120375	94.68	0.0001
SUMP	2	183.37056726	91.68528363	230.49	0.0001
STORIES*SUMP	4	13.84806062	3.46201516	8.70	0.0001
AGE*SUMP	4	58.66063551	14.66515888	36.87	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	8.75183666	4.37591833	11.00	0.0001
STRUCT	6	14.35304889	2.39217481	6.01	0.0001
AGE*STRUCT	4	3.27535605	0.81883901	2.06	0.0837
STORIES	2	53.14685179	26.57342590	66.80	0.0001
SUMP	2	1.43556533	0.71778266	1.80	0.1646
STORIES*SUMP	4	12.25185120	3.06296280	7.70	0.0001
AGE*SUMP	4	58.66063551	14.66515888	36.87	0.0001

Table B5 ANOVA Table for Ellsworth AFB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	503.29876586	35.94991165	132.04	0.0001
Error	1363	376.55220526	0.27227202		
Corrected Total	1397	879.85097112			

R-Square	C.V.	Root MSE	RADLOG Mean
0.572027	38.90225	0.52179692	1.34130261

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	2	175.25649612	87.62824806	321.84	0.0001
STRUCT	6	277.68168829	46.28028138	169.98	0.0001
FOUND	3	31.97315846	10.65771949	39.14	0.0001
DRAIN	2	4.42060755	2.21030378	8.12	0.0003
HEAT	1	13.96681541	13.96681541	51.30	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	8.87522939	4.43761470	16.30	0.0001
STRUCT	6	103.97573202	17.32928867	63.65	0.0001
FOUND	3	25.26790126	8.42263375	30.93	0.0001
DRAIN	2	5.73335865	2.86667933	10.53	0.0001
HEAT	1	13.96681541	13.96681541	51.30	0.0001

Table B6 ANOVA Table for Peterson AFB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	30	169.89162364	5.66305412	36.51	0.0001
Error	653	101.27579892	0.15509311		
Corrected Total	683	271.16742256			

R-Square	C.V.	Root MSE	RADLOG Mean
0.626519	-180.5651	0.39381862	-0.21810335

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	4	53.69209162	13.42302291	86.55	0.0001
STRUCT	10	89.72059280	8.97205928	57.85	0.0001
AGE*STRUCT	12	8.50921425	0.70910119	4.57	0.0001
HEAT	4	17.96972497	4.49243124	28.97	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	4	3.24931091	0.81232773	5.24	0.0004
STRUCT	10	13.50404479	1.35040448	8.71	0.0001
AGE*STRUCT	12	6.62162499	0.55180208	3.56	0.0001
HEAT	4	17.96972497	4.49243124	28.97	0.0001

Table B7 ANOVA Table for USAF Academy

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	28	196.61981135	7.02213612	9.94	0.0001
Error	1178	832.27219309	0.70651290		
Corrected Total	1206	1028.89200444			

R-Square	C.V.	Root MSE	RADLOG Mean
0.191099	78.27743	0.84054322	1.07380019

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	7	30.76139032	4.39448433	6.22	0.0001
STRUCT	9	83.24006573	9.24889619	13.09	0.0001
FOUND	3	61.66852631	20.55617544	29.10	0.0001
STRUCT*FOUND	9	20.94982898	2.32775878	3.29	0.0006

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	7	17.88106148	2.55443735	3.62	0.0007
STRUCT	9	9.09072214	1.01008024	1.43	0.1702
FOUND	3	5.09514393	1.69838131	2.40	0.0660
STRUCT*FOUND	9	20.94982898	2.32775878	3.29	0.0006

Table B8 ANOVA Table for Bergstrom AFB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	234.53179080	15.63545272	49.02	0.0001
Error	925	295.04501012	0.31896758		
Corrected Total	940	529.57680092			

R-Square	C.V.	Root MSE	RADLOG Mean
0.442866	-1813.949	0.56477215	-0.03113496

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	4	30.97655694	7.74413923	24.28	0.0001
STRUCT	7	148.91980296	21.27425757	66.70	0.0001
STORIES	1	50.21901415	50.21901415	157.44	0.0001
STORIES*STRUCT	3	4.41641676	1.47213892	4.62	0.0033

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	4	27.74267599	6.93566900	21.74	0.0001
STRUCT	3	3.80345815	1.26781938	3.97	0.0079
STORIES	1	14.50501275	14.50501275	45.47	0.0001
STORIES*STRUCT	3	4.41641676	1.47213892	4.62	0.0033

Table B9 ANOVA Table for Nellis AFB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	278.24973730	23.18747811	110.93	0.0001
Error	1710	357.44942759	0.20903475		
Corrected Total	1722	635.69916490			

R-Square	C.V.	Root MSE	RADLOG Mean
0.437707	-3212.590	0.45720319	-0.01423161

Source	DF	Type I SS	Mean Square	F Value	Pr > F
STRUCT	3	192.47454980	64.15818327	306.93	0.0001
AGE	4	28.54481997	7.13620499	34.14	0.0001
AGE*STRUCT	5	57.23036753	11.44607351	54.76	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
STRUCT	3	65.33297274	21.77765758	104.18	0.0001
AGE	4	25.44249217	6.36062304	30.43	0.0001
AGE*STRUCT	5	57.23036753	11.44607351	54.76	0.0001

Table B10 ANOVA Table for Edwards AFB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	138.81203124	8.16541360	92.99	0.0001
Error	2324	204.07309180	0.08781114		
Corrected Total	2341	342.88512304			

R-Square	C.V.	Root MSE	RADLOG Mean
0.404835	-1055.305	0.29632945	-0.02807999

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	3	77.63114794	25.87704931	294.69	0.0001
STRUCT	8	44.74213166	5.59276646	63.69	0.0001
STORIES	2	10.15518555	5.07759277	57.82	0.0001
FOUND	3	3.09076428	1.03025476	11.73	0.0001
FUEL	1	3.19280178	3.19280178	36.36	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	68.44094291	34.22047145	389.71	0.0001
STRUCT	8	8.05113241	1.00639155	11.46	0.0001
STORIES	2	9.76550670	4.88275335	55.61	0.0001
FOUND	3	3.07528732	1.02509577	11.67	0.0001
FUEL	1	3.19280178	3.19280178	36.36	0.0001

Table B11 ANOVA Table for Aviano AB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	31	142.95035411	4.61130175	9.60	0.0001
Error	341	163.78026679	0.48029404		
Corrected Total	372	306.73062091			

R-Square	C.V.	Root MSE	RADLOG Mean
0.466045	41.36734	0.69303249	1.67531319

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	5	17.44312059	3.48862412	7.26	0.0001
STRUCT	8	72.56261395	9.07032674	18.88	0.0001
AGE*STRUCT	11	22.63218896	2.05747172	4.28	0.0001
STORIES	3	25.69084524	8.56361508	17.83	0.0001
AGE*STORIES	4	4.62158537	1.15539634	2.41	0.0494

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	5	6.04636746	1.20927349	2.52	0.0295
STRUCT	8	46.21572712	5.77696589	12.03	0.0001
AGE*STRUCT	10	15.96501565	1.59650157	3.32	0.0004
STORIES	3	1.91067723	0.63689241	1.33	0.2657
AGE*STORIES	4	4.62158537	1.15539634	2.41	0.0494

Table B12 ANOVA Table for Lajes AB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	205.64997786	12.09705752	20.20	0.0001
Error	727	435.46708787	0.59899187		
Corrected Total	744	641.11706573			

	R-Square	C.V.	Root MSE	RADLOG Mean
	0.320768	133.5852	0.77394565	0.57936475

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	5	19.80362571	3.96072514	6.61	0.0001
STRUCT	7	126.02587700	18.00369671	30.06	0.0001
FOUND	3	23.40038569	7.80012856	13.02	0.0001
AIR	2	36.42008945	18.21004472	30.40	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	5	41.79811966	8.35962393	13.96	0.0001
STRUCT	7	40.48518730	5.78359819	9.66	0.0001
FOUND	3	20.82120151	6.94040050	11.59	0.0001
AIR	2	36.42008945	18.21004472	30.40	0.0001

Table B13 ANOVA Table for Andersen AFB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1020.70190988	92.79108272	108.84	0.0001
Error	1783	1520.02327131	0.85250885		
Corrected Total	1794	2540.72518119			

R-Square	C.V.	Root MSE	RADLOG Mean
0.401736	84.40532	0.92331408	1.09390506

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	5	922.01419268	184.40283854	216.31	0.0001
STRUCT	5	91.90151383	18.38030277	21.56	0.0001
AGE*STRUCT	1	6.78620338	6.78620338	7.96	0.0048

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	4	395.49288414	98.87322103	115.98	0.0001
STRUCT	5	98.22421965	19.64484393	23.04	0.0001
AGE*STRUCT	1	6.78620338	6.78620338	7.96	0.0048

Table B14 ANOVA Table for Yokota AB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	25	237.58256734	9.50330269	20.43	0.0001
Error	1405	653.58248230	0.46518326		
Corrected Total	1430	891.16504964			

	R-Square	C.V.	Root MSE		RADLOG Mean
	0.266598	1135.167	0.68204345		0.06008308

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	4	34.14990509	8.53747627	18.35	0.0001
STRUCT	7	87.34973561	12.47853366	26.82	0.0001
STORIES	5	35.71695134	7.14339027	15.36	0.0001
FOUND	4	64.37341742	16.09335436	34.60	0.0001
FUEL	2	11.15490473	5.57745236	11.99	0.0001
HEAT	3	4.83765314	1.61255105	3.47	0.0157

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	4	12.90762476	3.22690619	6.94	0.0001
STRUCT	7	88.84287817	12.69183974	27.28	0.0001
STORIES	5	43.52078072	8.70415614	18.71	0.0001
FOUND	4	63.57311280	15.89327820	34.17	0.0001
FUEL	2	6.67463111	3.33731556	7.17	0.0008
HEAT	3	4.83765314	1.61255105	3.47	0.0157

Table B15 ANOVA Table for Kadina AB

The SAS System

General Linear Models Procedure

Dependent Variable: RADLOG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	37	1323.66369774	35.77469453	59.19	0.0001
Error	5763	3483.34636787	0.60443282		
Corrected Total	5800	4807.01006560			

R-Square	C.V.	Root MSE	RADLOG Mean
0.275361	144.7232	0.77745278	0.53719997

Source	DF	Type I SS	Mean Square	F Value	Pr > F
AGE	6	335.18412329	55.86402055	92.42	0.0001
STRUCT	8	487.85997507	60.98249688	100.89	0.0001
AGE*STRUCT	23	500.61959938	21.76606954	36.01	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	6	49.11421779	8.18570296	13.54	0.0001
STRUCT	8	127.49942165	15.93742771	26.37	0.0001
AGE*STRUCT	23	500.61959938	21.76606954	36.01	0.0001

Appendix C

LSMEANS Tables

Table C1 LSMEANS Output for Grissom AFB

Age	Struct	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
5	1	2.8	1.09
5	6	2.6	1.76
5	2	1.6	1.03
2	2	0.82	1.49
4	2	0.65	1.07
4	1	0.59	1.06
3	2	0.59	1.06
3	1	0.52	1.33
3	3	0.50	1.76

Table C2 LSMEANS Output for Wright-Patterson AFB

Attribute	Value	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
Age	2	0.60	1.36
	4	0.54	1.29
	5	0.54	1.29
	7	0.32	1.31
	6	0.32	1.41
	3	0.22	1.29
Struct	1	1.22	1.30
	2	1.10	1.28
	6	0.90	1.29
	4	0.51	1.35
	11	0.25	1.50
	5	0.18	1.32
	9	0.07	1.39
Fuel	4	1.00	1.23
	1	0.98	1.22
	2	0.33	1.23
	3	0.22	1.50
	5	0.18	2.09
Air	2	0.49	1.19
	4	0.45	1.25
	3	0.33	1.26
	1	0.27	2.07

Table C3 LSMEANS Output for Chanute AFB

Age	Struct	Found	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
5	1	1	4.2	1.25
4	2	1	3.4	1.23
4	1	1	3.1	1.11
3	4	2	2.1	1.28
5	2	1	2.0	1.03
4	2	2	1.9	1.37
3	2	1	1.6	1.09
3	5	2	1.2	1.03
2	5	2	1.2	1.17
5	1	3	1.1	1.47
4	5	2	1.1	1.09
3	6	2	1.1	1.05
5	3	3	0.89	1.09
5	2	3	0.83	1.03
5	5	1	0.80	1.05
5	9	3	0.79	1.28
5	2	2	0.69	1.14
1	6	2	0.52	1.11
5	10	2	0.50	1.11
6	9	1	0.33	1.15

Table C4 LSMEANS Output for Grand Forks AFB

Age	Struct	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
4	4	2.9	1.26
5	2	1.9	1.32
5	1	1.8	1.54
4	1	1.5	1.18
5	6	1.4	1.51
4	3	1.4	1.44
4	2	1.3	1.05
5	5	1.0	1.36
3	2	1.0	1.14
4	5	0.95	1.10
4	12	0.85	1.88
3	5	0.71	1.18
3	6	0.18	1.19

Table C5 LSMEANS Output for Ellsworth AFB

Attribute	Value	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
Age	1	1.0	1.19
	4	0.88	1.18
	5	0.70	1.17
Struct	2	2.9	1.16
	1	2.4	1.18
	11	1.0	1.30
	5	0.93	1.21
	4	0.80	1.29
	6	0.65	1.21
	9	0.14	1.36
Found	2	3.2	1.20
	1	1.3	1.13
	4	0.50	1.27
	5	0.27	1.48
Drain	2	1.0	1.17
	1	0.45	1.15
Heat	1	0.98	1.18
	2	0.76	1.17

Table C6 LSMEANS Output for Peterson AFB

Age	Struct	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
2	1	1.4	1.51
2	8	1.2	1.51
1	5	1.2	1.15
4	1	1.1	1.14
3	1	1.0	1.15
5	11	1.0	1.16
5	8	1.0	1.22
4	3	0.99	1.36
4	2	0.85	1.13
4	8	0.81	1.35
3	4	0.79	1.20
3	8	0.77	1.16
3	11	0.75	1.15
2	11	0.74	1.51
3	10	0.73	1.35
1	11	0.72	1.29
3	2	0.65	1.14
3	3	0.59	1.13
3	6	0.58	1.15
3	9	0.58	1.51
5	10	0.58	1.51
2	6	0.55	1.16
4	10	0.50	1.51
4	11	0.44	1.29
4	5	0.41	1.14
3	7	0.41	1.51
3	5	0.33	1.14

Table C7 LSMEANS Output for USAF Academy

Struct	Found	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
4	2	5.0	2.48
2	1	4.0	1.22
7	1	3.7	2.37
5	5	2.9	2.37
1	1	2.1	1.25
11	2	1.9	1.31
8	1	1.9	1.53
6	1	1.5	1.38
10	2	1.5	2.62
2	5	1.4	1.36
1	2	1.4	2.37
5	2	1.3	1.45
2	2	1.3	1.31
2	4	1.2	1.29
11	5	1.1	1.51
6	4	1.0	1.45
8	2	1.0	1.40
11	1	0.99	1.36
10	1	0.63	1.87
9	1	0.58	2.37
11	4	0.57	1.87
1	5	0.50	1.25

Table C8 LSMEANS Output for Bergstrom AFB

Age	Struct	Stories	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
5	1	1	2.1	1.07
4	1	1	2.0	1.16
5	3	1	1.8	1.12
4	6	2	1.8	1.12
3	2	1	1.5	1.10
5	3	5	1.3	1.73
5	2	1	1.3	1.03
1	2	1	1.2	1.73
2	5	3	1.0	1.28
4	2	1	0.7[illegible]	1.73
5	5	3	0.53	1.04
5	2	2	0.52	1.09
5	3	2	0.52	1.07
3	9	2	0.51	1.20
1	6	1	0.51	1.09
5	8	1	0.50	1.73
5	6	3	0.46	1.12
3	4	1	0.44	1.20
3	5	3	0.40	1.73
5	5	1	0.40	1.73

Table C9 LSMEANS Output for Nellis AFB

Age	Struct	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
4	4	2.0	1.29
5	1	1.7	1.52
4	1	1.4	1.20
5	2	1.2	1.35
5	6	1.2	1.21
3	2	1.2	1.05
3	5	0.95	1.09
4	2	0.83	1.02
5	5	0.78	1.11
4	3	0.63	1.52
4	5	0.63	1.06
4	12	0.40	2.07
3	6	0.29	1.13
4	9	0.25	1.67

Table C10 LSMEANS Output for Edwards AFB

Attribute	Value	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
Struct	6	0.96	1.07
	3	0.95	1.08
	1	0.94	1.07
	2	0.93	1.07
	5	0.88	1.07
	7	0.82	1.08
	8	0.67	1.09
	4	0.57	1.12
	9	0.32	1.36
Found	3	1.1	1.16
	4	0.75	1.08
	1	0.63	1.11
	2	0.59	1.06
Fuel	2	0.99	1.06
	3	0.56	1.11

Table C11 LSMEANS Output for Aviano AB

Age	Struct	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
5	8	18	1.77
4	7	17	1.77
5	7	16	1.39
4	10	8.8	2.12
9	8	8.4	1.76
5	6	7.3	1.39
5	10	5.6	1.53
5	4	5.2	2.12
3	10	4.8	2.12
5	8	4.3	1.36
9	1	4.2	1.44
1	9	4.1	1.64
5	11	3.9	1.37
3	11	3.4	1.49
4	8	3.3	1.38
4	6	3.2	1.40
4	11	3.2	1.49
2	11	3.0	2.12
5	5	2.7	1.34
3	8	2.7	1.34
3	7	2.4	1.41
1	8	2.3	1.42
4	5	2.2	1.39
1	11	2.1	1.63
2	8	1.9	2.12

Table C12 LSMEANS Output for Lajes AB

Attribute	Value	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
Age	6	2.8	1.47
	3	2.2	1.28
	4	1.5	1.20
	2	1.4	1.19
	1	0.99	1.19
	5	0.58	1.22
Struct	7	7.3	1.33
	5	2.5	1.26
	2	1.9	1.27
	1	1.9	1.34
	3	1.4	1.31
	11	0.80	1.25
	9	0.69	1.55
	4	0.29	1.57
Found	5	2.0	1.49
	4	1.8	1.40
	2	1.4	1.10
	3	0.77	1.14
Air	2	3.1	1.20
	1	1.8	1.19
	3	0.49	1.28

Table C13 LSMEANS Output for Andersen AFB

Age	Struct	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
6	1	8.0	1.08
4	11	5.6	1.34
4	2	4.6	1.03
3	3	4.0	1.10
4	1	3.2	1.08
3	2	2.4	1.07
5	2	2.0	1.11
9	4	1.4	1.42
5	1	0.86	1.09
5	5	0.70	1.09
1	5	0.52	1.11
5	6	0.51	1.27

Table C14 LSMEANS Output for Yokota AB

Attribute	Value	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
Age	3	0.71	1.17
	9	0.62	1.15
	2	0.46	1.18
	5	0.45	1.20
	6	0.14	1.15
Struct	3	1.0	1.44
	7	0.88	1.27
	2	0.84	1.26
	5	0.44	1.28
	6	0.40	1.27
	1	0.32	1.28
	4	0.27	1.49
	9	0.08	1.54
Stories	4	0.66	1.22
	3	0.58	1.25
	1	0.47	1.22
	9	0.43	1.62
	2	0.29	1.21
	10	0.25	1.60
Found	2	0.55	1.27
	5	0.54	1.40
	1	0.47	1.27
	4	0.32	1.22
	3	0.29	1.22
Fuel	1	0.66	1.25
	4	0.51	1.26
Heat	4	0.55	1.25
	1	0.29	1.27
	2	0.29	1.29

Table C15 LSMEANS Output for Kadina AB

Age	Struct	Geometric mean Radon Concentration (pCi/L)	Geometric Standard Deviation (pCi/L)
6	1	10	1.08
3	1	5.2	1.21
3	5	5.2	1.11
2	8	4.6	2.18
3	6	3.9	1.24
4	2	3.8	1.04
2	1	3.2	1.16
4	3	3.2	1.04
9	1	2.9	2.18
4	1	2.9	1.08
3	2	2.7	1.18
1	1	2.3	1.30
3	7	2.1	1.73
5	1	2.0	1.03
4	7	2.0	1.11
4	5	1.9	1.06
2	5	1.8	1.11
5	3	1.8	1.20
1	7	1.7	1.09
3	11	1.6	1.32
3	3	1.6	1.05
2	2	1.5	1.07
1	2	1.4	1.05
2	3	1.4	1.03
5	5	1.4	1.03
1	6	1.4	1.14
4	11	1.3	2.18
2	7	1.3	1.05
1	3	1.2	1.05
5	7	1.2	1.07
5	11	1.0	1.32
5	2	1.0	1.05
2	11	0.93	1.48
6	3	0.83	1.07
2	4	0.82	1.21
4	6	0.80	1.07
6	5	0.62	1.14
5	6	0.58	1.12

Appendix D

PROC MEANS Output for Grissom AFB

The SAS System

General Linear Models Procedure

Student-Newman-Keuls test for variable: RADLOG

NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha= 0.05 df= 630 MSE= 0.592078
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 1.990136

Number of Means	2	3	4
Critical Range	1.5147695	1.8121543	1.9869772

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	STRUCT
A	0.9555	1	6
A			
A	0.1199	506	2
A			
A	-0.0405	126	1
A			
A	-0.6931	1	3

```
                     The SAS System                  11:57 Friday, June 5, 1992   3

                General Linear Models Procedure

          Student-Newman-Keuls test for variable: RADLOG

NOTE: This test controls the type I experimentwise error rate under the complete null
      hypothesis but not under partial null hypotheses.

            Alpha= 0.05  df= 630  MSE= 0.337 19
             WARNING: Cell sizes are not equal.
           Harmonic Mean of cell sizes= 7.72[illegible]02

          Number of Means         2         3         4
          Critical Range  0.5801762 0.6940785 0.7610379

Means with the same letter are not significantly different.

            SNK Grouping            Mean       N  AGE

                       A          0.5250     365  5

                       B         -0.1928       2  2
                       B
                       B         -0.4819     150  4
                       B
                       B         -0.5382     117  3
```

General Linear Models Procedure

Student-Newman-Keuls test for variable: RADLOG

NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha= 0.05 df= 632 MSE= 0.357246
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 166.5377

Number of Means	2	3
Critical Range	0.1276586	0.1529603

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	STORIES
A	0.51370	360	1
B	-0.43216	113	2
B			
B	-0.49769	162	3

General Linear Models Procedure

Student-Newman-Keuls test for variable: RADLOG

NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha= 0.05 df= 632 MSE= 0.594727
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 2.621342

Number of Means	2	3
Critical Range	1.3227955	1.5824692

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	FUEL
A	1.2238	1	3
A			
A	0.1090	7	1
A			
A	0.0853	627	2

```
                         The SAS System                  11:40 Friday, June 5, 1992   3

                General Linear Models Procedure

           Student-Newman-Keuls test for variable: RADLOG

NOTE: This test controls the type I experimentwise error rate under the complete null
      hypothesis but not under partial null hypotheses.

              Alpha= 0.05  df= 631  MSE= 0.58108
              WARNING: Cell sizes are not equal.
            Harmonic Mean of cell sizes= 42.84273

         Number of Means        2         3         4
         Critical Range   0.323427 0.3669231 0.4242503

Means with the same letter are not significantly different.

         SNK Grouping              Mean       N  AIR

                    A            0.3580      13  2
                    A
           B        A            0.1685     289  3
           B        A
           B        A            0.1031     212  1
           B
           B                    -0.1632     121  4
```

The SAS System 11:56 Friday, June 5, 1992 3

General Linear Models Procedure

Student-Newman-Keuls test for variable: RADLOG

NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha= 0.05 df= 632 MSE= 0.590952
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 1.997693

Number of Means	2	3
Critical Range	1.5103782	1.6068984

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	HEAT
A	1.7405	1	6
B	0.0869	632	2
B			
B	-0.6020	2	1

```
                    The SAS System                    11:53 Friday, June 5, 1992   3

              General Linear Models Procedure

         Student-Newman-Keuls test for variable: RADLOG

NOTE: This test controls the type I experimentwise error rate under the complete null
      hypothesis but not under partial null hypotheses.

            Alpha= 0.05  df= 633  MSE= 0.584435
             WARNING: Cell sizes are not equal.
           Harmonic Mean of cell sizes= 36.66299

                 Number of Means        2
                 Critical Range  0.3496772

Means with the same letter are not significantly different.

        SNK Grouping             Mean      N  SUMP

                   A           0.1061    616  1

                   B          -0.5197     19  2
```

General Linear Models Procedure

Student-Newman-Keuls test for variable: RADLOG

NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha= 0.05 df= 632 MSE= 0.489948
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 230.0726

Number of Means 2
Critical Range 0.1281558

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	DRAIN
A	0.27023	483	1
B	-0.49241	151	2

General Linear Models Procedure

Student-Newman-Keuls test for variable: RADLOG

NOTE: This test controls the type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha= 0.05 df= 633 MSE= 0.469279
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 238.3748

Number of Means 2
Critical Range 0.1258179

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	FOUND
A	0.27573	476	2
B	-0.47655	159	1

```
CMS FILEDEF TEST DISK grissom data a;
DATA test;
INFILE test;
INPUT struct 61-63 stories 64-66 age 67-68 found 69-71 air 72-73
heat 74-76 fuel 77-78 drain 81-82 sump 83-84 radon 154-160;
radlog = log (radon);
proc glm;
  class stories;
model radlog= stories;
means stories/ snk;
run;
```